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The effect of compost and priming on the salt tolerance of bread wheat (Triticum aestivum L. cv. S-24 and cv. Slambo) during germination and early seedling establishment

Gadeh, Hussam M

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THE EFFECT OF COMPOST AND PRIMING ON THE SALT TOLERANCE OF BREAD WHEAT (*Triticum aestivum* L. cv. S-24 and cv. Slambo) DURING GERMINATION AND EARLY SEEDLING ESTABLISHMENT

HUSSAM M GADEH

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Abstract

Soil salinity and the arid climate in Libya are major constraints in agriculture and predominantly in foodstuff production which are limiting wheat production and yield. The effect of pre-sowing seed treatments with 50 mM of KCl, NaCl, $CaCl_2$, and distilled water as hydropriming on germination and early seedling growth in two wheat (*Triticum aestivum* L.) cultivars S-24 (tolerant) and Slambo (untested before) under 0, 100, 200 and 300 mM NaCl concentrations was examined. $CaCl_2$ was the only priming treatment that significantly improved the germination percentage, germination rate, and mean germination time in both cultivars under almost all NaCl concentrations. Thus, priming with $CaCl_2$ was selected for further experiments. In the greenhouse, seeds primed with 50 mM of $CaCl_2$ also improved the emergence percentage, emergence rate, shoot and root length, and fresh and dry weight of shoots and roots of both cultivars under all NaCl concentration except at 300 mM where the emergence was completely inhibited. The response of wheat cultivars to three compost treatments including cow manure compost (CC), greenwaste compost (GC) and 50:50 mixture (mix) between them and sand at percentage inclusions of 10 and 30 % by weight under 0, 100, 200, and 300 mM of NaCl was also investigated. Among all compost treatments, 30% GC and 30% mix were the best treatment and improved almost all growth parameters under salt stress, and 30% GC was also the only treatment that had any emergence at 300 mM NaCl. 30% GC and 30% mix were selected for further experiments.

The effect of the combination of the selected priming agent ($CaCl_2$) and the best two compost treatments (30% GC and 30% mix) on the emergence and early seedling growth of both cultivars was tested. The results showed that all the treatments enhanced plant growth parameters including seedling ion uptake in both cultivars, with preference to primed seeds sown in 30% GC. The treatments had the following order of the performance of both

cultivars under salt stress. Primed seeds sown in 30% GC > unprimed seeds sown in 30% GC > primed seeds sown in 30% mix > unprimed seeds sown in 30% mix. This enhancement is possibly due to the provision of Ca^{2+} and / or the improvement in the availability of water as both of them were improved by the application of priming and compost.

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ANOVA	Analysis of Variance
Ca^{2+}	Calcium
K^{+}	Potassium
Mg^{2+}	Magnesium
Fe^{2+}	Iron
Na^{+}	Sodium
P	Phosphorus
Cl^{-}	Chloride
$1/t_{50}$	The reciprocal of the time in days taken to complete 50% of final germination
EC	Electrical conductivity
GC	Greenwaste Compost
CC	Cow Compost
Mix	Mixture between cow and greenwaste composts
S	Shoor
R	Root
G%	Germination Percentage
GR	Germination Rate
MGT	Mean Germination Time
E%	Emergence Percentage
ER	Emergence Rate
MET	Mean Emergence Time

Chapter 1
Introduction

1.1. Introduction

Crops are subjected during their life cycle to many stresses that limit their growth and productivity. These stresses include drought, high salinity, and low temperature (Nakayama *et al*. 2000). The response of crops to these stresses varies among species (Ghiyasi *et al*. 2008; Haidarizadeh and Zarei 2009; Akman 2009). Amongst these stresses, soil salinity is a major problem that adversely influences the development and growth of crops, which leads to a decrease in the yield of the crops, particularly in arid and semi-arid regions (Ghiyasi *et al.* 2008; Fallah 2008; Ahmadi, Emam, and Pessarakli 2009; Mostafazadeh-Fard *et al.* 2009; Dkhil and Denden 2010; Abari *et al*. 2011). According to Haidarizadeh and Zarei (2009) as much as 25% of the world's total cultivated land is salt-affected. However, other studies have been estimated that 20% of the whole cultivated land around the world and 50% of irrigated land are salt-affected (Yokoi, Bressan, and Hasegawa 2002; Afzal *et al*. 2008; Moud and Maghsoudi 2008). Several factors can increase salinity problems including low precipitation, high surface evaporation, weathering of parental rocks, and human activities such as irrigation with saline or low quality water (Goudarzi and Pakniyat 2008). Salinity can affect the growth of crops and subsequently reduce the yield due to osmotic stress, ion toxicity and nutrient imbalance (Munns and Tester 2008; Gwanama *et al*. 2009; Haidarizadeh and Zarei 2009). High concentrations of salt around the root zone increase the osmotic pressure in the soil solution resulting in inhibition of water uptake by crops causing physiological drought. Furthermore, the growth of crops can be decreased due to ion toxicity as a result of high accumulation of salt in the plant (Munns and Tester 2008). Growth processes, including

germination, emergence, and seedling establishment, are the most vulnerable and can be affected by an increase in salinity (Atia *et al*. 2006; Akbari, Sanavy, and Yousefzadeh 2007). Germination is one of the most salt-sensitive plant growth phases and strongly hampered with rising salt concentrations in both glycophytes and halophytic plants (Atia *et al*. 2006; Dkhil and Denden 2010). High and rapid germination and emergence is crucial to obtain an optimal crop stand establishment that gives higher productivity (Harris *et al*. 2001; Wahid *et al*. 2008), but high concentrations of salinity can negatively affect plants and cause poor germination, emergence and seedling establishment (Afzal *et al*. 2006a). Salt resistance of seeds during the germination phase is critical for the establishment of plants that grow in saline environments. It has been reported that most seed species achieve their highest germination in distilled water and are very sensitive to salinity at early germination and seedling stages (Akbari, Sanavy, and Yousefzadeh 2007).

Wheat (*Triticum aestivum* L.) is considered to be one of the first domesticated crops and has been a staple food in North Africa, West Asia and Europe for more than eight thousand years (Curtis, Rajaram, and Macpherson 2002) and is the single most important crop planted for human food and animal feed (Colmer, Flowers, and Munns 2006; Akman 2009). It has been reported that wheat is a staple food for one third of the world's population and an important source of carbohydrates, fibre, vitamins, proteins, and provides nutrition for both human beings and animals (Basra, Pannu, and Afzal 2003; Rahman *et al.* 2008). More than 20% of the total calorie needs of the world's population are provided by wheat (Bushuk and Rasper 1994; Naseem *et al.* 2001). Globally, it is sown over a larger area than other commercial crops such as rice, maize and potatoes. It has been estimated that a total of 240 million ha are sown to wheat annually. However, wheat cultivated lands are affected by the increase of soil salinity and wheat yield is decreased due to the increase of salinity stress (Egamberdieva 2009; Masmoudi *et al*. 2009). Colmer, Flowers and Munns (2006) pointed

out that from 8 to 10% of the wheat cultivated land in India, Pakistan, Iran, Egypt, Libya and Mexico is now salt-affected and 6737 farms where wheat is the major sown crop are influenced by salinity. Wheat is considered to be a moderately salt resistant crop (Saboora *et al.* 2006; Islam *et al*. 2007; Haidarizadeh and Zarei 2009). Cuin *et al.* (2008) and Masmoudi *et al*. (2009) pointed out that sodium exclusion from the leaves is one of the main mechanisms conferring salt tolerance in wheat. Shirazi *et al*. (2005) claimed that the discrimination between K^+ and Na^+ is the most important characteristic correlated to salt tolerance in wheat. In order to raise the yield of crops in a saline stressed environment, the enhancement of salt tolerance is very important (Azooz 2009). Due to the increase of the salinity problem and decrease of wheat productivity, many treatments have been used to improve the salt tolerance of wheat including gypsum, fertilizers such as compost, and technical treatments such as priming.

Compost has been found to enhance the growth of wheat. Compost positively influences the growth and health of plants (Jacques and Mohamed 2004) and is believed to be an important source of plant nutrients and organic matter that increases the nutrients absorbable by plants (Tilston *et al.* 2005; Organic Farming Systems 2008). Tilston *et al.* (2005) and Ibrahim *et al.* (2008) reported that the growth and yield of wheat is improved by the use of compost. Lakhdar *et al*. (2008) found that the productivity of irrigated crops with saline water or crops grown under saline stress can be enhanced by using compost as an amendment.

Priming is a procedure which partially hydrates the seed and then allows them to dry so that germination processes begins but radicle emergence does not occur (Giri and Schillinger 2003; Dezfuli, Sharif-Zadeh, and Janmohammadi 2008). Priming is easy to use, its cost is low, and there are no risks with its use (Iqbal and Ashraf 2005; Bakare and Ukwungwu 2009). Seed priming has been successfully confirmed to enhance germination percentage, germination rate and emergence in seeds of many crops such as maize, wheat, rice, canola,

sugar beet, sunflower and soybean (Kaya *et al*. 2006; Ghiyasi *et al*. 2008; Salehzade *et al*. 2009). Assorted seed priming techniques have been used, including osmopriming, hydropriming, halopriming, thermopriming and hormone priming (Ashraf and Foolad 2005; Golezani *et al*. 2008; Ashraf *et al.* 2008; Tzortzakis 2009). Harris (2004) suggests that wheat seed priming has been successful in countries such as India, Nepal and Pakistan. It has also been reported that hydropriming improved the germination, seedling establishment and yield of barley under saline and non-saline conditions (Rashid *et al.* 2006). Moreover, osmopriming has also been reported to be successful for enhancing the germination of wheat seeds under stress conditions (Ghiyasi *et al.* 2008). Furthermore, Afzal *et al* (2008) claimed that the salt tolerance of wheat was considerably improved by using halopriming under saline conditions compared with the other treatments. Harris *et al* (2005) also indicated that halopriming can increase the yield of maize, wheat and chickpea.

Compost also has been reported to improve the growth of plants. Ibrahim *et al.* (2008) reported that the addition of different concentrations of compost (300, 400 and 500 kg ha^{-1}) enhanced the growth of wheat. Moreover, Lawson, Hayatsu, and Nioh (2004) concluded that the growth of kidney bean, soybean and alfalfa under saline conditions was improved when compost was added to the soil. The present study is therefore conceived with the following aim and objectives:

1.2. Aim

To evaluate the effect of compost and priming on the salt tolerance of bread wheat during germination and early seedling establishment.

1.3. Objectives

1- To determine the effect of seed priming treatments on seed germination of bread wheat under saline and non-saline conditions.

2- To determine the effect of application of composts on seed emergence of bread wheat under saline and non-saline conditions.
3- To compare the effect of pre-sowing treatments and the application of compost on the salt tolerance of bread wheat during emergence and seedling establishment.
4- To understand the mechanisms that improve salt tolerance of bread wheat induced by both techniques.
5- To determine the optimum priming method and assess its practical feasibility for use by Libyan Farmers.

Chapter 2
Literature Review

2.1. Soil Salinity

Some environmental stresses negatively influence plant growth, development and overall crop productivity. Salinity, drought and nutrient imbalances are the major environmental stresses. It has been reported that less than 10% of the world's arable lands are free from these environmental stresses, with drought and salinity being the most widespread (Goudarzi and Pakniyat 2008). Salinity stress remains one of the oldest and most serious environmental problems, which adversely influences and substantially obstructs the growth and productivity of crops particularly in arid and semi arid areas (Qayyum, Shahbaz, and Akram 2007; Fallah 2008; Goudarzi and Pakniyat 2008; Mostafazadeh-Fard *et al.* 2009; Dkhil and Denden 2010; Abari *et al*. 2011; Bhutta 2011) where precipitation is not sufficient and water supplies are also scarce as compared to water needed for crop production (Unlukara *et al*. 2010).

Soil salinity is defined as the increase in the accumulation of salts such as sodium chloride, sodium carbonate, and sodium sulphate (Alamgir, Musa, and Ali 2007). There are a number of other definitions, Ashraf and Foolad (2005) defined soil salinity as the existence of an excessive content of absorbable salts, which impede or influence the growth of crops. A saline soil can be also defined as a soil which consists of an adequate amount of dissoluble salts which can hamper the growth of crops (James, Hanks, and Jurinak 1982).

Different units are used in measuring soil salinity (Table 2.1) but deci Siemens per metre ($dS\ m^{-1}$) is the most common unit.

Table 2.1. Units and conversion coefficients used to express salinity (Gucci and Tattini 1997).

Salinity index	Unit	Conversion coefficient
Electrical conductivity	dS m^{-1}	1
NaCl concentration	mM, meq l^{-1}	10-12
	mg l^{-1}	580-700
Total soluble salt	%	~0.064
	ppm	~640
Osmotic pressure	MPa	0.036

According to Munns and Tester (2008) soil can be classified as saline when the electrical conductivity (EC) equals or exceeds 4 dS m^{-1}. This concentration of salt can decrease crop production extensively. Soil salinity is categorized as per the following Table 2.2.

Table 2.2. Soil salinity classification (Chhabra 1996)

Soil salinity class	Electrical conductivity (dS m^{-1})	Influence on crop
Non-saline	< 2	Salinity effects negligible
Slightly saline	2 – 4	Yield of sensitive crops may be restricted
Moderately saline	4 – 8	Yield of many crops restricted
Strongly saline	8 – 16	Only tolerant crops survive
Very strongly saline	>16	Only a few very tolerant crops

Pessarakli (1994) reported that saline soils can be classified into five types. Firstly, saline soil that occurs due to the effect of electrolytes of sodium salts. This soil can be formed in desert and semi-desert regions. Secondly, alkaline soil which is produced due to the effect of electrolytes of alkaline hydrolysis. This kind of soil is found in all climatic regions. Thirdly, soil which is salt-affected by $CaSO_4$ or $CaCl_2$. It can be formed in arid and semi-arid regions (North America, North Africa, the Middle and Far East, and Australia). Fourthly, saline soil which is induced by magnesium which occurs in desert and semi-desert regions. It can also be formed in semi-humid regions. Finally, acid sulphate soil which is formed as a result of

$Al_2(SO_4)_3$ and $Fe_2(SO_4)_3$ accumulation. This soil can occur throughout the world in regions close to seacoast and in tidal marsh areas.

2.1.1. Causes of Salinity

Many factors can affect the formation of, or increase in, soil salinity. These factors include the weathering of minerals from parent material rocks (Munns and Tester 2008; Ozturk *et al*. 2009), and deposition of oceanic salts carried in wind and rain (Ozturk *et al*. 2009). Also soils may become saline as a result of human activities such as irrigation practices, which increase salt accumulation in arid and semi-arid regions **(**Noori, Roustaei, and Foghi 2006). Furthermore, in tropical and subtropical regions, deforestation processes are considered as a main source of salinity (Chan 2001). Moreover, chemical fertilizers can also contribute to producing saline soil when they are used excessively (Chhabra 1996). Many other factors can cause salinity including dust deposited on the soil, herbicides, insecticides, fungicides, and solid wastes can cause salt surface deposition **(**Munns and Tester 2008).

Weathering Reactions

Salts can be formed as result of weathering process. The significant supply of all soluble salts is the chemical weathering of rock minerals in the exposed layer of the earth's crust. Weathering processes, including hydrolysis, hydration, oxidation, carbonation and many other processes decompose minerals in rocks. These processes discharge dissoluble ions that join together to form salts. The type of ions released depends on the kind of rocks which are exposed to weathering processes but are mainly sodium chloride, calcium chloride and magnesium chloride (Munns and Tester 2008). The geochemical processes that are involved in weathering reactions depend on the efficient elimination of the weathering products from the reaction location. The reaction of weathering processes can form salts that are not related to the rocks.

Surface Deposition

Many sources can contribute soluble salts, mainly rainwater, irrigation water, dust deposited on the soil, herbicides, insecticides, fungicides, and solid wastes. Rainwater carries from 6 to 50 mg kg^{-1} of NaCl. This amount of NaCl decreases as the distance from the coast increases (Munns and Tester 2008). However, Munns (2009) and Ozturk *et al*. (2009) estimated that rainwater distributes 10 kg ha^{-1} of sodium chloride for every 100 mm of rainfall yearly**.**

Cultivated lands increase in line with the need to produce more food, which leads to more irrigation practices. The increase of irrigation practices drives the increase in salt accumulation in soil. The use of bad quality or slightly saline irrigation water can cause increase in soil salinity over time. Lakhdar *et al*. (2008) reported that irrigation with poor water is one of the main causes increasing salt accumulation and reducing crops yield. Deef (2007) and Unlukara *et al*. (2010) declared that 50% or more of irrigated areas around the world are exposed to the effects of salinization and water logging. Moreover, Curtis, Rajaram, and Macpherson (2002) mentioned that irrigation water might carry from 1 to 4 kg m^{-3} of soluble salts yearly presenting 1-60 t ha^{-1} annually of soluble salts. According to the FAO (2009), secondary salinity, which is caused by human activities, has affected over 30 million ha of the estimated 1,500 million ha of agricultural land. However, Patel *et al*. (2010) reported that over 40 million ha of irrigated area are affected by salinity, which is approximately one third of the whole irrigated area in the world. However, Sattar, Hussnain, and Javaid (2010) reported that about 50% of whole irrigated lands in the world are affected by salinity.

Deforestation

It has been estimated that 9 million km^2 of the globe's arid lands have been turned into man-made deserts over the past half century (Tavili *et al*. 2011). Salinity has also occurred in

tropical and subtropical regions due to deforestation processes (Bhutta 2011). It is believed that it is due to migration of ions in the soils. For instance, trees use ground water as a source of water for their growth; when the trees are felled, the soil water table is increased due to the filtration of rain water and irrigation water (Chan 2001). Thus, dissolved salts from raw rock material are raised with the water to the depth close to the surface of soil. Consequently as a result of the evaporation process, salts are lifted to the surface of the soil causing salinity (Chan 2001). For instance, in India wild regions of former forest become extremely saline in a few years after the removal of the trees (Pessarakli 1994).

Contamination with Chemicals

Although the quantity of chemical fertilizers, which are used in agriculture, is low compared with amount of salt in some soils, they have also been considered year after year as a major source of salinity which occurs due to intensive agricultural production, especially in greenhouses where chemical fertilizers are often heavily used. In addition, several sources such as sewage sludge and industrial emissions can increase the accumulation of some ions causing saline soil which leads to reduction in the productivity of soil (Pessarakli 1994; Chhabra 1996; Bond 1998).

2.1.2. Distribution of Salt-affected Soils

There is a shortage of information about salt affected soils around the world, although several studies have attempted to estimate the area which is affected by salinity. For instance Haidarizadeh and Zarei (2009) estimated that 25% of the whole of the cultivated world's land is affected by salinity and 33% of it is irrigated land. Moud and Maghsoudi (2008), and Sattar, Hussnain, and Javaid (2010) estimated that 19% of the 2.8 billion ha of agricultural land are affected by salinity in the world. Furthermore, Unlukara *et al*. (2010) reported that

about 40,000 ha of agricultural area become unavailable for agricultural production every year because of the increase of soil salinity. Saboora *et al.* (2006) mentioned the salt affected soils are estimated at 3.5 million ha and that most of it is associated with cotton, rice, wheat, sugarcane and rapeseed cultivation.

According to Farooq (2009) total salt-affected soil around the world is about 955 million ha. Australia is the most affected area with about 357 million ha, followed by North and Central Asia with 212 million ha. Africa has 81 million ha. In Libya 950,700 ha of cultivated land are salt-affected (Hachicha and Abdelgawed 2003) and are located in the north along the coast (Ben-Mahmoud 2001). Salt-affected soil in Libya is also found as scattered spots throughout the pre-desert and desert areas, mainly in the wadis and oases. These soils are not suitable for crop production. Ben-Mahmoud (2001) reported that in the coastal areas of Libya, 12% of northwest (200,000 of 1.6 million ha) and 23% of north east (332,000 of 1.4 million ha) (Figure 2.1) are salt-affected, and substantial areas of agricultural lands in being becoming salt-affected due to irrigation activites. The level of salts differs among these soils. For instance, the EC of in Sebrata area is 74.0 dS m^{-1}, in Misurata is 50.2 dS m^{-1}, while in the east of Libya is 18.6 - 47.8 dS m^{-1}(Ben-Mahmoud 2001).

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Figure 2.1. Soil salinity of Libya (LIB 2004)

2.1.3. The Effects of Soil Salinity on Plants

Salinity affects crop by causing poor germination and seedling establishment. It has been reported that during germination and early seedling establishment, plants are more sensitive to salinity (Dhanapackiam and Ilyas 2010). The mechanisms of growth inhibition as affected by salinity include the osmotic or water deficit effect and specific ion excess effect (Blumwald, Aharon, and Apse 2000; Flowers and Flowers 2005; Salama, Mansour, and Hassan 2011). The osmotic effect is the decreasing of osmotic potential due to the high accumulation of ions in the solution of growth medium, which reduces the ability of plant to take up water and leads to decreased growth. The ion specific effect is described as the increase of toxic ions (e.g Na^+, Cl^-) in the plant tissue with a decrease in beneficial ions (e.g K^+, Ca^{2+}), thus decreasing plant growth (Munns 2002; Munns and Tester 2008; Karimi, Abdolzadeh, and Sadeghipour 2009; Khayatnezhad *et al*. 2010; Salama, Mansour, and Hassan 2011). Sayar *et al*. (2010a, 2010b) and Abari *et al*. (2011) reported that salt affected

soils contain enough soluble salts to restrict the growth of, and cause damage to plants through a series of interacting factors such as osmotic potentialand ion toxicity. The latter might not be expected to have an immediate effect as plants have a reserve of nutrients that they can mobilize (Akram *et al.* 2007). Furthermore, it has been reported that the germination of seeds may be affected by soil salinity either by creating osmotic potential external to the seeds, which inhibits water uptake or by the toxic effects of Na^+ and Cl^- ions on germinating seeds (Janmohammadi, Dezfuli, and Sharifzadeh 2008; Mohammadi 2009; Patel *et al*. 2010). Distinguishing between these two types of stress is important to understand the physiological mechanisms for the salinity tolerance of plants (Munns and Tester 2008). Moreover, Physiological and biochemical processes can be impacted by both osmotic and ionic stresses (Alamgir, Musa, and Ali 2007; Azooz 2009).

Osmotic Effect

In the osmotic effect, water uptake of plants can be limited by salinity due to a reduction in the osmotic potential of the growth medium (Dixit and Chen 2010). The osmotic pressure of soil increases by the increase of soluble salts which affect the ability of plants to absorb sufficient amounts of water (Epstein 1980). Tavili *et al*. (2011) reported that the increase in salt concentration in the soil results in a reduction in water potential, which influences water availability. Water shortage or osmotic effects are probably the main physiological mechanisms for growth reduction as salinity stress reduces the soil water potential. When salts are accumulated around the root zone, the osmotic pressure will be increased to the threshold level. Therefore, the plants will be affected directly and leaf and shoot growth rate dramatically decreases. The emergence rate of new leaves will be slower than usual and the development of lateral buds will also be slow or will stay dormant. These effects are a result of the osmotic impact of the accumulation of ions in the rooting zone. Normally the most

rapid response by plants to osmotic stress, which is presented due to drought or increased salinity, is to reduce the consumption of water by closing stomata or decreasing the leaf surface area. However, these mechanisms may affect the exchange of gases and the ability of the leaf to reduce the temperature of the plant caused by transpiration processes. Also long periods of osmotic stress lead to extension of the roots to attain deeper soil moisture and transfer it to the plant (Epstein and Bloom 2005). The number of tillers in the whole leaf area is heavily influenced by the increase of salinity in cereal crops (Munns and Tester 2008). The reduction in water uptake by the plant from the soil is due to the decrease in leaf production, which leads to the retention of moisture in the soil, preventing salt uptake. In addition, the evapotranspiration process can also be affected by the increase of salinity (Chhabra 1996). This effect is due to the decrease in the availability of water as a result of the decrease in osmotic potential, reduction in leaf area and higher maintenance of water in the plant to reduce the absorbed salts (Chhabra 1996).

Ionic Effect

In this effect**,** high accumulation of ions in the growth medium or in the plant itself may cause toxicity to the plant. Therefore, the normal growth of plants will be affected (Chhabra 1996). When concentration of salts in the old leaves rise to toxic levels this causes death of the old leaves. Moud and Maghsoudi (2008) reported that when the rate of transpiration is high, salt will be concentrated in the leaf causing it to die. Moreover, Neumann (1997) reported that when ions are accumulated in the transpiring leaves (old leaves), leaf senescence and necrosis are accelerated. Consequently, the provision of carbohydrates and hormones are reduced. Munns and Tester (2008) mentioned that in low and moderate concentrations of salinity, the ionic effect has less effect on the growth than the osmotic effect.

Ion toxicity may affect the cell membrane. As the regulation of the exchange of materials between the cell and the surrounded environment is an important function of cell membrane, the accumulation of salts leads to the destruction of the membrane structure and the replacement of Ca^{2+} by Na^{+} at the binding sites (Jacoby 1994). This effect on membrane structure produces enhanced membrane permeability and ion leakage from the cell (Bewley and Black 1994). It has been reported that Ca^{2+} decreases the effect of salinity on membrane integrity (Easterwood 2002; Iqbal 2005; Afzal *et al*. 2008) by maintaining the selectivity of K^{+}: Na^{+} ratio (Royo and Abio 2003; Gobinathan, Murali and Panneerselvam 2009).

2.1.4. Mechanisms of Adaptation to Salinity

Crop research for salinity tolerance has become increasingly important because of the need to increase the productivity of crops in saline areas (Strogonov 1964; Epstein 1980). Due to the increase in population, it is very important to increase the production of wheat to overcome the serious difficulties in sustaining a wheat food supply (Curtis *et al*. 2002). Better wheat production can be attained in two methods: (1) increasing the area of wheat cultivated lands including saline and acid soils, (2) increasing the production of wheat per unit area sown (Curtis *et al*. 2002). The salt tolerance of plants is defined as the capability of plants to grow in a saline environment (Parida and Das 2004). Chhabra (1996) reported that it is difficult to fix a limit of salinity where the plant will fail to grow. Plant salinity tolerance is a complex phenomenon process which varies between species and different varieties (Azooz 2009). This difference in tolerance is based on a number of factors including plant physiology and growth stage (Chhabra 1996; Azooz 2009). Crops vary in their salinity tolerance. Figure 2.2 shows the diversity in salt tolerance of different crop species, presented as increases in shoot dry matter after growth in solution or sand culture containing NaCl for at least three weeks, relative to a control species (Saltbush). According to Munns and Tester (2008) rice (*Oryza*

sativa) is very sensitive to salinity. On the other hand, salinity tolerance of barley (*Hordeum vulgare*) is high. Wheat (*Triticum aestivum* L.) is considered to be moderately tolerant.

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Figure 2.2. Salinity tolerance among the various crop species (Munns and Tester 2008)

Furthermore, plants can be categorized according to their ability to tolerate saline conditions into two types, namely halophytes and glycophytes. Halophytes are defined as plants that are relatively tolerant to high levels of salinity and can accumulate relatively high concentrations of Na^+ and Cl^- in their tissues. Abari *et al*. (2011) reported that halophytes have adapted to salt stresses by their ability to adjust somatically. On the other hand, glycophytes are not tolerant of high concentrations of salt in their roots zones or able to hold high levels of Na^+ and Cl^- in their tissues (Epstein 1980). Halophytic plants can also effectively avoid uptake of Na^+ and Cl^- by roots when saline water is absorbed, whereas, glycophytes can not avoid uptake of Na^+ and Cl^- in highly saline soil**.** Sea barley grass is an example of a halophyte, which can grow and exclude sodium and chloride from its tissues in a very saline environment with up to 450 mM of NaCl (Garthwaite, von-Bothmer, and Colmer2005). Strogonov (1964) suggests that halophytic plants can grow in an environment of 0.3 – 20%

salinity. Conversely, Orcutt and Nilsen (2000) reported that 10% of salinity can prevent the growth of glycophytic plants.

Soil osmotic pressure can be increased by the increase of salt concentration in soil and as a result, the plant faces difficulty in taking up an adequate amount of water from soil. However, halophytes have high osmotic pressure in their cell sap because they hold a high concentration of salt in their tissues. Therefore, halophytes can overcome the osmotic pressure of soil (Munns and Tester 2008). However, plants can only grow or stay alive in saline soil if they can both maintain water uptake and exclude a vast percentage of the salt in the soil solution (Munns 2009). Three different strategies or physiological salt tolerancesare used by plants in order to adjust to soil salinity, namely, tolerance to osmotic stress, the exclusion of Na^+ and Cl^- , and plant tissue tolerance to accumulated Na^+ and Cl^- (Munns and Tester 2008).

Tolerance to Osmotic Stress

Many plants can use inorganic salts to increase their own osmotic pressure to an equal level with the soil osmotic pressure in order to extract water (Chhabra 1996). This process is called osmotic adjustment. Ashraf and Foolad (2005) and Flowers and Colmer (2008) reported that organic (compatible) solutes can be used as osmotic adjusters. Moreover, plants also can use inorganic salts such as Na^+, Cl^- , K^+ and Ca^{2+} to adjust their own osmotic potential (Ashraf 2004). In new leaves and root tips, osmotic stress affects the plant by decreasing cell expansion and encouraging stomatal closure. With greater leaf growth and stomatal conductance, the response to osmotic stress would be decreased but in plants which have enough available water, the leaf area would be increased due to synthesis of sufficient carbohydrates especially in irrigated lands where water is guaranteed (Munns and Tester 2008).

Exclusion of Na^+ and Cl^-

Plants are able to avoid absorbing salts which are not needed for growth, using their roots. Roots can avoid absorbing Na^+ to prevent accumulation at toxic levels in the leaves. This selective avoidance of ions is achieved via the cell membrane (Chhabra 1996).

To avoid salt concentrating in the shoots, roots must exclude 98% of the soluble salts, permitting just 2% to be moved through the xylem to the shoots (Munns 2009). Cereals differ in terms of salt exclusion. In 50 mM NaCl, Janz cultivar can exclude 99% of soluble salts while bread wheat can exclude 98%. However, durum wheat, rice and barley exclude 94% of soluble salts (Munns 2005).

The adaptation to Na^+ toxicity is not the only thing that is required for salt tolerance, the acquisition of K^+ is also required for salt tolerance, but because of the chemical similarity of K^+ and Na^+ ions, the high accumulation of Na^+ in the root zone influences the absorption of K^+ (Rodríguez-Navarro 2000). It is suggested that the transport systems of K^+, which involve good selectivity of K^+ over Na^+ can be considered a significant salt tolerance determinant (Rodríguez-Navarro 2000). Bagcl, Ekiz, and Yilmaz (2007) reported that the key trait contributing to salt tolerance is the discrimination of K^+ over Na^+. Also Aslam *et al.* (2003) reported that Na^+ ions that entered into the shoots are accumulated in the old leaves. On the other hand, the transportation of K^+ ions is continued and these K^+ ions are accumulated in the younger leaves. Any deficiency in excluding Na^+ leads to toxicity. This effect can occur in days or weeks depending upon the kind of plant (Munns and Tester 2008).

Tissue tolerance requires disassociation of Na^+ and Cl^- at the cellular and intracellular level to limit Na^+ accumulation and avoid toxicity in the cytoplasm. Plants should be able to compartmentalize the salt in vacuoles, thus the cytoplasm will be protected from ion toxicity, and prevent dehydration by avoiding a build-up of salts in the cell wall (Flowers and Yeo

1986; Munns 2009). Otherwise, the salt will be concentrated in the cells and cause death to the old leaves (Munns 2009).

2.2. Wheat (*Triticum aestivum* L.)

Wheat (*Triticum aestivum* L.) is one of the world's major cereal crops, and a staple crop for about 35% of the human population (Datta *et al*. 2009; He *et al*. 2010; Khan *et al*. 2010). It is one of the cereal crops which are a member of the grass family. The most common uses of cereal crops are as food, feed or coarse grains (Bushuk and Rasper 1994). It has been estimated that land crops supply 90% of world's food and 68% of which is provided by the main cereal crops such as wheat, corn, rice, barley and sorghum. Fruits, vegetables and tubers supply 22% (Bushuk and Rasper 1994). Cereal crops provide more than half of the human requirement for protein and energy. Globally, they are grown on about two-thirds of all planted lands. It is also believed that cereal crops have been cultivated as a source of human food since ancient times. Furthermore, they are very important crops due to their simple mode of growth, storage and mobilization as well as their nutritional value (Adaptations of Cereals 2009). Because of this adaptability, cereal crops are also able to grow in a variety of climates. For instance, wheat can be grown in regions of high or low temperature, drylands where irrigation is involved, and in areas with high rainfall (Adaptations of Cereals 2009).

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Figure 2.3.Wheat (*Triticum aestivum* L.) (Natural Resources Conservation Service 2009)

2.2.1. The Importance of Wheat *(Triticum aestivum* L.*)*

Common wheat *(Triticum aestivum* L.*)* is a widespread crop around the world. It is an extremely important food crop. In 2004, global wheat production was 627 million tonnes (Timothy, Timothy, and Munns 2006). In 2010 the global wheat production had been increased to 682 million tonnes (World Top Ten Wheat Producers 2010). Wheat contributes more protein and calories to the world's diet than any other food crop (Ali *et al*. 2006). It provides the world's population with almost 20% of their total calories (Naseem *et al.* 2001). In addition, it is the best source of carbohydrate (Hanaa and El-Baky 2009) and its starch is not hard to digest. Wheat also contains vitamins, fats and minerals (Bushuk and Rasper 1994). Moreover, wheat seeds contain high quantities of a variety of phenolic compounds includes phenolic acids, anthocyanidins, quinines, flavonoids and amino phenolic compounds, which provide potential health benefits (Hanaa and El-Baky 2009). Wheat is the main source of world's bread flour. It can be used for alcoholic drinks and beer. Furthermore,

the bran of wheat is used as a food for livestock. Wheat straw is used to make baskets and floor carpets (Duke 1983). Table 1.3 shows the typical chemical analysis of wheat seed.

Table 2.3. Typical content of wheat *(Triticum aestivum* L.*)* seed per 100 g (Duke 1983)

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2.2.2. Wheat in Libya

Wheat is considered to be one of the most important crops in Libya where it covers one fifth of the total agricultural land 80% of wheat in Libya is planted under a rain-fed system while the rest is grown under irrigation in the coastal areas and oases of Kofra in the south. It has been estimated that the area suitable for rain-fed cereal crop production in Libya is between 500,000 ha and 800,000 ha confined in a narrow band in the north along the coast, and a few irrigated areas on secluded oases. Cereal land was 484,000 ha in 1984, wheat and barley occupied 257,000 and 214,000 ha respectively of it, and irrigation covered about 15% of wheat land. Figure 1.3 shows the wheat production areas in Libya.

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Figure 2.4. Major and minor wheat production areas in Libya (USDA 2004)

According to the Libya-FAO wheat database (2005), between 1974 and 1985 the production of wheat significantly increased from 82,000 t $year^{-1}$ to 181,000 t $year^{-1}$ due to the Agriculture Development Plan. However, by 2000, production had dropped to 160,000 t $year^{-1}$due to some environmental factors such as a rarity of suitable soils, limited ground water resources, and insufficient and unreliable rainfall (Libya- FAO wheat database 2005). The production of wheat in Libya accounts for only 15-20% of the required need in Libya, such that 1.4 million tonnes of wheat are imported every year to cover the deficit (USDA 2004).

Wheat in Libya is also affected by soil salinity, Timothy, Timothy, and Munns (2006) reported that 8–10% of wheat planted area in Iran, Pakistan, Egypt, India, Mexico and Libya is impacted by the increase of salt affected soil.

2.2.3. The Effect of Salinity on Wheat (*Triticum aestivum* L.)

Like other crops, the production of wheat can be affected by both soil and water salinity. Salinity in the root area has negative impacts on the growth of wheat. The influence of salinity can be extremely harmful for wheat. Even though wheat is grown under both irrigated and rain-fed conditions, both types of agriculture are threatened by salinization (Qayyum, Shahbaz, and Akram 2007). Curtis, Rajaram, and Macpherson (2002) reported that the yield of wheat was decreased up to 50% by an increase in salinity to 13 dS m^{-1}. It has been reported that the low yield of wheat under salinity stress is often attributed to low seed germination, emergence and poor establishment of seedlings (Abro, Mahar, and Mirbahar 2009). Seed germination and seedling establishment are the most sensitive phases to salt stress in many cropsand are critical stages of the crop life cycle (Atia *et al*. 2006; Dkhil and Denden 2010).

Akbari, Sanavy, and Yousefzadeh (2007) reported that rapid seed germination and seedling establishment are important factors for crop yield in saline environments in arid and semi-arid regions. Many studies of seed germination under salt stress have shown that seeds of most crop species obtain their greatest germination in distilled water, and germination and seedling stages are decreased with an increase in salt level (Gulzar, Khan, and Ungar 2003; Akbari, Sanavy, and Yousefzadeh 2007). Kaya *et al* (2009) studied the effect of salinity on germination and seedling establishment, and their results revealed that germination and emergence of wheat seeds were negatively affected by NaCl and the mean germination time was delayed. Saboora *et al.* (2006) studied the effect of salinity on nine wheat cultivars and the results showed that the increase of salt concentration had a negative effect on germination %, germination rate, and shoot and root dry weight. They also reported that, in the first phases of growth, wheat is highly sensitive to saline environments. The growth of seedlings can be affected by salt accumulation by reducing the speed of mobilization of the reserve

nutrients. Soil salinity affects the emergence of wheat and reduces by 50% with 8.8 dS m^{-1} soil salinity. However, Monasterio *et al.* (2002) reported that soil salinity affects wheat yield when electrical conductivity is greater than 6 dS m^{-1}. Generally the germination percentage, rate and growth of wheat are also affected by salinity. Furthermore, Fallah (2008) investigated the effects of salt stress on four wheat cultivars, and the results indicated that germination percentage, germination rate, the length of shoot and root, and dry weight of shoots and roots were diminished with the increase of NaCl in all cultivars. Rahman *et al.* (2008) also reported that the presence of high concentrations of NaCl in the soil reduces the weight and the length of shoots and roots in wheat. Haidarizadeh and Zarei (2009) studied the effect of different concentrations of sodium chloride on seedling establishment in wheat and the results showed that the growth of shoots and roots significantly decreased with an increase in NaCl concentration. Also they reported that the total number, leaf weight, and leaf length were affected by the increase of NaCl. Moreover, it has been reported that leaf cell expansion and leaf area can be decreased by accumulation of salts in the plant (Ahmad, Abid, and Azam 2009). The length of the stem can be also affected due to the increase of Na^+ in the tissues (Naseem *et al.* 2001). It has also been reported that salt accumulated in the soil leads to a reduction in the quantity of leaves in the main shoot and reduces the quantity of spikelets in the main spike (Naseem *et al.* 2001; Curtis, Rajaram, and Macpherson 2002). The viability of tillers is also affected by salinity. The number of primary and secondary tillers is reduced with the increasein salt concentrationto 7.5 dS m^{-1} in the soil (Curtis, Rajaram, and Macpherson 2002). Grieve, Francois, and Maas (1994) highlight that all phenological phases in wheat are hastened by salt accumulation in soil. The decreasing quantity of culms is the main aspect of growth that is affected by salinity (Maas *et al.* 1994).

2.3. Alleviation of Salt Stress

Poor germination and seedling establishment are the outcomes of soil salinity. It is a vast problem negatively affecting growth and development of crop plants and causing low agricultural production (Afzal *et al*. 2006b). Ozturk *et al*. (2009) reported that about 82% of crops' potential productivity is lost as a result of abiotic stress annually, and the amount of suitable agricultural land continues to decline the world over, leading to agriculture being practised on lands where the abiotic stress is even higher. As mentioned previously, salt stress decreases plant growth and crop yield. Improved tolerance to salinity stress in crops is necessary in order to increase productivity with limited water supplies and high levels of salinity (Azooz 2009). So it is very important to increase the production by enhancing crop salt tolerance under these conditions, thus improving food security for the growing human population as well as for the benefit of poor farmers world-wide (Ashraf, Ozturk, and Athar 2009).

Many treatments can be used in order to enhance the performance of wheat in a saline environment. These treatments include soil amendments such as gypsum and compost, and technical treatments such as priming. The latter has been found to increase the resistance of wheat to salinity during germination and early seedling establishment, to enhance disease resistance and to give a better yield.

2.3.1. Compost as a Growing Medium

Compost can be defined as "the product resulting from the controlled biological decomposition of organic material" (Darlington 2001). In other words, compost is a supplier of plant nutrients (Ibrahim *et al*. 2008).

Compost also positively affects the growth and the health of plants by supplying nutrients, improving the capacity for water retention and enhancing the condition of soil

(Jacques and Mohamed 2004). Compost can be made from different kinds of feed stocks, including gardenwaste or trimmings**,** biosolids (sewage sludge), wood by-products, animal manures, crop residues, leaves, biodegradable packing, and food scraps such as kitchen and vegetable scraps. In the UK, the most common raw materials used to produce compost come from households, parks and gardens.

Composting Process

The composting process is defined as "a process of controlled biological decomposition of biodegradable materials under managed conditions" (WRAP 2004). From this definition, it is obvious that composting is a biological process. Therefore, this process does not include substances of inorganic origin (Golueke 1991). The composting process is achieved by microorganisms such as bacteria and fungi which use the organic materials to provide their food and energy (Christian and Evanylo 2009). A suitable microorganism population is necessary to activate the composting process. Furthermore, the quantity of microorganisms is a good indicator of the activity of the compost (Golueke 1991).

The conditions of high temperature and moisture continue while the controlled composting process guarantees that most human and animal pathogens, and weed seeds are inhibited. The temperature used for the decomposition process is between 43 and 65°C (Christian and Evanylo 2009), and soil moisture content is between 50 and 60%, in addition to an appropriate amount of oxygen being available. Christian and Evanylo (2009) reported that the decomposition process may need 2–6 months in order to be completed, depending on local conditions. The difference between composts in nutrient content is related to the type of material which is used in the decomposition process. If the main material is manure, weeds or grass, a high level of nitrogen will be present (Compost Fundamentals 2007) but if the main material is corn stalk, litter or straw, less nitrogen will be present (Compost Fundamentals

2007). Carbon is the most abundant element present in compost and may form half of all compost mass. High quality compost dry weight consists of 50% or more of organic matter (Darlington 2001). In addition, pH of compost is mostly between 6 and 8. This range depends on the raw material of compost. For instance, pH of compost that is formed from wood remains or peat moss may be 4.5 or less, whereas that formed from manure may vary from 8.0 to 8.5 (Darlington 2001). The variability between values is related to the difference in the raw materials which are used in the decomposition process.

The Beneficial Effects of Compost

Compost enhances plant growth in a number of ways. The physical structure of soil can be improved by the use of compost by decreasing bulk density, improving workability, improving the porosity and water permeability of soil, and increasing soil water holding capacity (Aggeliides and Londra 2000). This reduces the frequency of the irrigation practices and increases drought resistance.

The addition of compost to the soil modifies the pH of the soil. For instance, pH of acidic soil will be increased to the neutral level if slightly alkaline compost is added. Compost is also considered as a main source of plant nutrients and organic matter that increases the nutrients absorbed by the plant (Tilston *et al.* 2005; Ibrahim *et al.* 2008). Composts provide plants with a range of nutrients particularly N, P, K (Table 2.4). Since compost contains relatively stable sources of organic matter, these nutrients are supplied in a slow release form (Nevens and Reheul 2003; and Ibrahim *et al*. 2008).

Increased organic matter leads to improved activity, population and diversity of soil organisms. Microorganisms play a vital role in the decomposition of organic matter, which leads to humus formation and nutrient availability (Compost and Plant Nutrition 2008). An adequate level of organic matter encourages earthworm activity making water infiltration and

aeration more effective because of their tunnelling (Jacques and Mohamed 2004; Tilston *et al*. 2005).

Table 2.4.The typical nutrient content of compost (Compost Fundamentals 2007).

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The Effect of Compost on Plant Growth

A number of studies have investigated the effect of adding compost on wheat growth and yield. Ibrahim *et al.* (2008) conducted pot studies to investigate the effect of raw organic manure and compost on the growth and yield of wheat (*Triticum aestivum* L. cv. Inqlab-91). Different concentrations of raw manure (10, 20, 30 and 40 Mg ha^{-1}) and compost (300, 400, and 500 kg ha^{-1}) were used. Wheat height, number of tillers, spike length and 1000-grain weight were increased significantly over control levels by using organic manure and compost separately. The maximum height of wheat increased by 16% by using compost at 500 kg ha^{-1} compared with the control. Also the maximum number of tillers per pot (29) was recorded by applying compost at 500 and 300 kg ha^{-1}, and then (28.3) by applying compost at 400 kg ha^{-1}. Furthermore, the fresh weight of wheat was increased by 44% when 400 kg ha^{-1} of compost was used and 27% when 30 kg ha^{-1} of organic manure was used compared to control. Tilston *et al.* (2005) also observed in their research that the yield of wheat increased after the application of compost.

Compost has also been found to improve the growth of plants under salt stress. Lawson, Hayatsu, and Nioh (2004) studied the effect of two composts (Bark and Tenporon) on the growth of kidney beans, soybeans and alfalfa under different concentrations of salinity (0, 50, 100, 150 and 200 mM). The results showed that the growth of kidney beans, soybeans and alfalfa was improved by the application of compost and the inhibitory effect of high concentrations of salinity was also alleviated by the application of compost. Moreover, Tejada and Gonzalez (2003) investigated the effect of four different concentrations of crushed cotton gin residues compost (20, 40, 60 and 90 t ha^{-1}) on wheat (*Triticum aestivum cv.* Cajeme) yield under dry land conditions. They reported that yield parameters such as number of grains per spike, the weight of 1000 grains, spike number per m^2, and the yield of wheat were increased by increasing the amount of compost. The number of grains per spike was increased from 40 in control plants to 47 in treated plants with the application of compost at 60 t ha^{-1}. Also they reported that the yield of wheat was increased from 3246 kg ha^{-1} in the control to 3519 kg ha^{-1} by using 60 t ha^{-1} of compost. Furthermore, Lakhdar *et al.* (2008) conducted a pot experiment in the greenhouse to investigate the effect of municipal solid waste (MSW) compost on *Hordeum maritimum* growth in a saline environment. Two concentrations of MSW compost (0 and 40 t ha^{-1}) were used, and plantswere irrigated with two concentrations of salinity (0 and 4 g l^{-1} NaCl). The results showed that nutrient uptake and the growth of *H. martiumum* under saline conditions can be enhanced by applying 40 t ha^{-1} of MSW compost. Also they found that the content of protein and chlorophyll were significantly increased. Thus, compost as an amendment can be utilized to improve the yield of crops with irrigated saline water or crops which are grown in a saline environment (Lakhdar *et al.* 2008).

2.3.2. Seed Priming

Priming is generally defined as a pre-germination seed treatment method in which the water potential of the seed is decreased to permit imbibition and some chemical alteration to occur but prevents the emergence of the radicle (Bradford 1986; Farooq *et al*. 2010a; Sadeghi *et al*. 2011; Umair *et al*. 2012). Zhao, Zhong, and Zhong (2009) defined priming "as a technique controlling hydration and drying that results in more rapid germination when the seeds are re-imbibed". Furthermore, Golezani *et al*. (2008) defined priming as a pre-sowing strategy for influencing the development of the seedling by modulating pre-germination metabolic activity prior to emergence of the radicle, which generally enhances germination rate and plant performance. It has been reported that the principle of a pre-soaking seed treatment relies on the fact that it is possible to hydrate seeds at a moisture level sufficient to initiate the early events of germination but not sufficient to permit radicle protrusion (Moradi and Younesi 2009).

Seed priming can be a low cost solution for poor farmers, it is reliable and simply adopted and also low risk intervention for ensuring fast germination (Harris 2004; Iqbal and Ashraf 2005; Bakare and Ukwungwu 2009; Tavili *et al*. 2011). Priming has been utilized to accelerate synchronized seed germination, encourage vigorous seedling establishment, and stimulate vegetative growth and crop yield in many field crops (Patade, Bhargava, and Suprasanna 2009). For exemple, maize, rice and wheat (Farooq *et al*. 2008; Moosavi *et al*. 2009; Zhao, Zhong, and Zhong 2009; and Golezani *et al*. 2010b). Moreover, seed priming has been effectively confirmed to enhance germination percentage and rate, and emergence percentage and rate mainly in vegetable seeds and small seeded grasses (Heydecker and Coolbear 1977; Bradford 1986; Sadeghi *et al*. 2011; Tavili *et al*. 2011). Furthermore, seed priming has been shown to enhance vigorous root growth regions of low soil water potential (Carceller and Soriano 1972). In addition, Moosavi *et al*. (2009) reported that pre-sowing

seed treatments improve the performance of seeds under adverse conditions and environmental stresses such as salinity. It has been reported that seed priming has recently been applied to overcome the salt stress problem on agricultural land (Tavili *et al*. 2011). Harris (2004) reported that priming is connected with improved disease resistance in some crops. For instance, in two different seasons in Bangladesh, the damage caused by collar rot (*Sclerotium rolfsii*) was decreased significantly due to seed priming in chickpea (Musa *et al.* 2001). It has been reported that the effects of priming treatment are associated with increased protein synthesis and the repair of membranes (Golezani *et al*. 2010a). During germination, the water uptake happens in three stages (Figure 2.5) (Bewley 1997).

Stage 1. This is the physical uptake of water into seeds. Rapid water uptake rate will occur in the stage due to the difference in water potential between the dry seed and the priming solution. DNA and mitochondria, protein synthesis, and metabolic activities occur during this stage.

Stage 2. In this stage, there is a little uptake of water but considerable metabolic activities occur as well as new physiological activities associated with germination such as the synthesis of mitochondria and proteins. In this stage seeds convert stored reserves such as proteins and fats into the compounds needed for germination.

Stage 3. In this stage, germination is completed and seedling growth is noticed by resumption of radical growth, identified by another increase in water uptake rate.

Several priming treatments can be used to enhance the performance of plants under stress conditions including hydropriming, osmopriming, halopriming, hormonepriming and thermopriming.

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Figure 2.5. Time course of major events associated with germination and subsequent postgerminative growth (Bewley 1997)

Seed Priming Techniques

Hydropriming

Hydropriming is the process through which seeds are soaked in water prior to sowing (Pill and Necker 2001). Water has been used successfully as a seed priming medium for wheat (Harris *et al.* 2001). However, seeds might be subjected to one or more drying cycles before germination. When this is the case, it is referred to as hardening. Soaking seeds of wheat in water before sowing can increase plant growth in stress conditions as compared with controls (Iqbal and Ashraf 2006). Rashid *et al.* (2006) reported that hydropriming increased the germination rate, enhanced yields and provided good establishment of barley under saline and non-saline soils. Harris (2004) reported that priming of wheat seed has proved to be useful in some countries such as India, Nepal and Pakistan. Saiki, Barman, and Ferrara

(2006) studied the effect of hydropriming for 12 h on six Indian wheat cultivars, and the results showed that the mean time for 50% emergence at 20°C decreased by two thirds, from 6 to 2 days. Golezanik *et al.* (2008) claimed that hydropriming can enhance seedling emergence rate, emergence percentage and seedling establishment of lentil (*Lens culinaris* Medik.) as well as increase the length of roots. Hydropriming by soaking in water for 12, 24, 36 or 48 h improved seed germination and increased maximum length of the radicle of two genotypes of maize (*Zea mays* L.) including B73 and MO17 (Dezfuli, Sharif-Zadeh, and Janmohammadi 2008). Numerous research efforts have concluded that treating crop seeds in water prior to sowing can enhance the resistance of crops to salinity (Zheng *et al.* 2002). By soaking maize in water, the resistance of seeds to salinity has been improved and gave better germination percentage compared with the control (Ashraf and Rauf 2001). Afzal *et al.* (2007a) studied the effects of several priming treatments (hydropriming, matriconditioning, chilling, osmopriming and hardening) on wheat (*Triticum aestivum* L.). They found that the maximum emergence percentage (61%) was obtained from hydropriming seeds followed by 24 h chilling. Also the maximum shoot length (18 cm) and root length (28 cm) were recorded by hydropriming seeds followed by 24 h of chilling.

Osmopriming

Heydecker, Higgins, and Gulliver (1973) defined osmotic seed priming as the soaking of seed in an osmotic solution, which permits the seeds to hydrate but prevents the extension of the radicle through the seed coat. Osmopriming is also referred to as osmotic conditioning. Osmopriming is important both in enhancing germination and developing the performance of crops under saline conditions. Osmotic seed priming does not need complex equipment and makes the results faster and easier to achieve (Foti *et al.* 2008). It can be achieved using polyethylene glycol (PEG), KNO_3, mannitol, KH_2PO_4, high molecular weight (HMW)

compounds, sugars and glycerol (Ashraf *et al.* 2008). PEG and mannitol are used as an osmotic priming material because they do not have a physiological reaction with the seed. However, PEG requires aeration which may not be available for poor farmers.

Salehzade *et al.* (2009) conducted an experiment to study the effect of PEG 8000 on germination and seedling growth of wheat (*Triticum aestivum* L.). They used PEG 8000 with different osmotic potentials (0, -0.3, -0.6 and -0.9 MPa). The results showed that the minimum time of 50% germination was recorded with -0.6 MPa of PEG (2 days), also they observed that the minimum mean germination time (3 days) was recorded at -0.3 MPa of PEG. The maximum shoot length (20.5 cm) and the maximum root length (9.1 cm) were recorded at an osmotic potential of -0.3 MPa. Therefore, they concluded that osmopriming enhanced germination and seedling vigour of wheat seeds. Moreover, Ghiyasi *et al.* (2008) studied the effect of PEG 8000 on wheat (*Triticum aestivum* L.) germination and seedling growth under saline conditions. Three osmotic potentials of PEG solutions (-0.4, -0.8 and -1.2 MPa) were used and seeds were subjected to four salinity levels (0, 4, 8, 12 and 16 dS m^{-1}). The results showed that osmopriming with PEG 8000 significantly increased seed germination and seedling growth. They reported that osmopriming is a successful practice for enhancing the germination of wheat (*Triticum aestivum* L.) seeds under saline conditions.

Halopriming

Soaking seeds in solutions of inorganic salts is defined as halopriming. Rafiq *et al*. (2006), Masoudi, Gazanchian, and Azizi (2010), and Jamal *et al*. (2011) reported that pre-sowing seed treatment with inorganic salts is an easy to use, low cost and low risk technique, and it is being successfully applied to overcome the salinity problem in agricultural lands.

Many reports show a considerable enhancement in seed germination, emergence, establishment and total production of different crops under saline conditions with

halopriming (Ashraf and Rauf 2001; Rafiq *et al*.2006). Mehta, Puntamkar, and Seth (1979) reported that the yield of wheat (*Triticum aestivum* L.) has been improved by soaking seeds in an inorganic salt solution. Since the yield and the growth of a wide range of crops can be limited by the presence of zinc, Harris *et al.* (2007) found that using $ZnSO_4$ as chemical priming solution increased the yield of wheat and maize. Harris *et al.* (2005) indicated that using $ZnSO_4$ as a halopriming agent increased the yield of maize by 26%, wheat by 16% and chickpea by 18%. Moreover, Mohammadi (2009) investigated the effect of priming with NaCl on seedling growth of canola (*Brassica napus* L.) in saline conditions, the results showed that NaCl priming increased germination percentage by 25.57%, germination rate by 34.67%, and the dry weight of seedlings by 36.67%. Furthermore, Iqbal and Ashraf (2007) studied the effect of halopriming on two spring wheat cultivars namely MH-97 (salt sensitive) and Inqlab-91 (salt tolerant). Seeds were soaked in 100 m molof $CaCl_2$, KCl or NaCl. The results showed that $CaCl_2$ followed by KCl and NaCl decreased the effect of salinity on grain yield and biomass production of both cultivars. Moreover, Afzal *et al.* (2008) investigated the effects of halopriming using $CaCl_2$, $CaSO_4$ and NaCl on two cultivars of wheat (Inqlab-91 and SARC-1) under non saline and saline (125 mmol NaCl) conditions and the results showed that the salt tolerance of both cultivars was considerably improved by using $CaSO_4$ under stress conditions compared with the other treatments. Also, the maximum root length was found in plants which were obtained from seeds primed with $CaSO_4$ and then $CaCl_2$. The lowest germination time of both cultivars of wheat was recorded by the use of $CaSO_4$ as a halopriming treatment. Also they reported that plants that were grown from seeds exposed to $CaCl_2$ or $CaSO_4$ had low accumulation of Na^+ and improved accumulation of K^+ and Ca^{2+} compared with the controls, which led to enhanced salinity tolerance. Sivritepe *et al.* (2005) suggested that halopriming can be a successful strategy to improve the salt tolerance of melons. Furthermore, Foti *et al.* (2008) studied the effect of different priming

treatments on the establishment of maize and the results showed that copper sulphate ($CuSO_4$) and zinc sulphate ($ZnSO_4$) significantly improved the emergence of seeds by 43% and 29%, respectively. On the other hand, the emergence of maize seeds primed with sodium sulphate ($NaSO_4$) was not significantly improved. On this basis they recommended copper sulphate as one of the best salts for seed priming treatments.

Hormonepriming

Many studies have shown that priming with plant growth hormones enhances the germination and the growth of various species of plants (Ashraf and Foolad 2005). The common regulators of growth can be gibberellin antagonists, gibberellins (GA), polyamines (Pas), kinetin, auxins (IAA, IBA and NAA), abscisic acid, salicylic acid (SA), ascorbic acid, brasinolide, ethylene and triacontanol (Ashraf *et al*. 2008).

Auxins as plant growth regulators have positive impacts on the percentage of seed crop germination especially in saline environments (Akbari, Sanavy, and Yousefzadeh 2007). Balki and Padole (1982) reported that soaking wheat seeds in IAA, NAA, and GA gives better germination in saline conditions. Also Akbari, Sanavy, and Yousefzadeh (2007) reported that by pre-soaking seeds of three wheat (*Triticum aestivum*) cultivars, Mahdavi, Pishtaz and Shiraz in auxin, germination and growth of cultivars was improved insalineconditions. Jamil and Rha (2007) studied the effect of gibberellic acid (GA_3) on germination and early seedling establishment of sugar beet in a saline environment. Three concentrations of GA_3 were used (100, 150 and 200 mg l^{-1}) and the results showed that germination and water uptake of primed seeds were positively affected by soaking seeds in GA_3. The time taken for germination was also reduced due to gibberellic acid. Salinity tolerance of plants can be increased by soaking seeds in salicylic acid as a form of hormonepriming (Iqbal and Ashraf 2006). It has been found that priming with salicylic acid

for 24 h increased the growth of wheat and also increased chlorophyll content as well as sugars which are important for osmotic adjustment under saline stress (Hamid *et al.* 2008). Moreover, Afzal *et al.* (2006b) reported that soaking wheat seeds in 50 ppm ascorbic acid and 50 ppm SA enhanced the final germination percentage and decreased the germination rate of wheat seeds under saline and optimum conditions. Furthermore, the greatest length and fresh and dry weight of shoots was reported in seedlings which were obtained from seeds primed with SA.

Thermopriming

Priming with temperature (thermopriming) means that seeds are exposed to high or low temperature in order to enhance germination percent, germination rate, and emergence of seedlings (Ashraf *et al*. 2008). Ashraf and Foolad (2005) claimed that priming with low temperature is commonly used to protect seeds from precocious germination in adverse environments. Moreover, Sharma and Kumar (1999) showed that the exposing of *Brassica juncea* seeds to low temperature at 5, 10 and 15°C improved germination percentage in saline conditions.

Although there are several priming methods, halopriming is the most commonly used technique. In this study hydropriming and halopriming will be used because of their low cost and consequently they are available for poor farmers in Libya as well as plant nurseries.

Factors Influencing Seed Priming Success

There are many studies demonstrating the beneficial effects of priming but negative effects of priming have also been reported in some studies. For example, Abdulrahmani *et al*. **(**2007) concluded that germination percentage of barley was reduced due to the application of priming. The same results were reported by Farooq *et al*. (2005a) with rice. Afzal *et al*.

(2004), Ashraf and Foolad (2005), and Abdulrahmani *et al*. (2007) reported that the beneficial effect of priming can be affected by some factors such as species, water potential of the priming solution, and soaking period. Thus there is no specific standard priming regime which can be used for all species andcultivars.

The Choice of Priming Agents

There are many priming agents that can be used but the outcome may be different. Thus there is no specific agent for each cultivar. Afzal *et al*. (2008) studied the effect of three halopriming agents on the growth of wheat under saline conditions and reported that $CaCl_2$ and $CaSO_4$ decreased the negative effect of salinity on the growth of wheat more effectively than NaCl. Moreover, it has been reported that germination percentage and germination rate of two wheat cultivars were improved under non-saline and saline conditions due to the application of $CaCl_2$ followed by hydropriming (Afzal *et al*. 2006a). Furthermore, Farooq *et al*. (2005b) studied the effect of three priming agents mainly halopriming with KNO_3 or NaCl and osmopriming with PEG 8000 on four tomato cultivars and the results showed that KNO_3 was the most effective agent for improving germination and seedling growth.

The Effect of Soaking Duration

Soaking period has been reported to be one of the key factors of determining the effectiveness of priming (Giri and Schillinger 2003; Subedi and Ma 2005; Dezfuli, Sharif-Zadeh, and Janmohammadi 2008). Yari, Aghaalikani, and Khazaei (2010) studied the effect of priming duration on germination and early growth of two wheat cultivars (Azar-2 and Sardari 101). Seeds were primed for 12 , 24 and 36 h in several priming agents (PEG 10%, PEG 20%, KCl 2%, KCl 4%, KH_2PO_4 0.5%, KH_2PO_4 1% and distilled water). The results showed that the greatest germination percentage was recorded in cv. Azar-2 when the seeds

were primed with PEG 20% for 12 h and the greatest stem length was obtained with seeds primed with PEG 10% for 24 h. Moreover, Yari *et al*. (2012) tested the effect of soaking three wheat cultivars (Fajer, Sherodi and Taram) for 12, 24 and 36 h in 0.5 and 1% $CaCl_2$ priming solutions. They concluded that soaking for 24 h was suitable for all three cultivars in terms of increasing the germination percentage. Many studies concluded that the duration of priming is different amoung the species and cultivars, for example, Rashid *et al*. (2006) reported that the best priming duration for soaking barley seeds was between 12 and 16 h. Furthermore, the best duration for maize and rice was 18 h (Harris *et al*. 1999; Harris 2004).

The Effect of Priming Agent Concentration

The concentration of the priming agent (osmotic potential) is also a critical factor. Afzal *et al*. (2007b) studied the effect of halopriming with 10, 25 or 50 mM NaCl and $CaCl_2$ in wheat (*Triticum aestivum* cv. Auqab-2000) under saline conditions. The results showed that most priming agents were not effective in improving germination and seedling estabishment under salt stress. However, primed seeds with 25 and 50 mM of $CaCl_2$ significantly reduced the mean germination time and significantly increased the shoot length, and fresh and dry weight of seedlings more than all priming treatments. Moreover, it has been reported that the effectiveness 150 and 200 mg l^{-1} GA_3 was better than 100 mg l^{-1} GA_3 in terms of increasing germination percentage and germination rate of sugar beet seeds as compared to the control under saline conditions (Jamil and Rha 2007). According to this, there is no specific standard concentration that can be used for all cultivars and varieties.

The Different Response of Cultivars and Species to Priming

Many studies have shown that there is variability among seeds in terms of their response to priming. Yari, Aghaalikani, and Khazaei (2010) noticed that there was a different response

between two wheat cultivars (Azar-2 and Sardare -101) to four priming treatments. The same results were obtained byYari *et al*. (2011) with the same wheat cultivars. Moreover, Afzal *et al*. (2006a) reported that the response of two wheat cultivars (Auqab-2000 and MH-97) to priming with ascorbate was different. The same results were concluded by Afzal *et al*. (2008) with two wheat cultivars (Inqlab-91 and SARC-1) primed in 50 mM of $CaCl_2$, NaCl and $CaSO_2$. It was also found by Yari *et al*. (2011) that three wheat cultivars (Fajer, Sherodi and Taram) responded differently to different concentrationsof $CaCl_2$ as the priming agent in pre-sowing treatments. Moreover, Dezfuli, Zadeh, and Janmohammadi (2008) also concluded that the response of two maize cultivars (B73 and MO17) to hydropriming, osmopriming and PEG-6000 was different.

Chapter 3

The Response of Wheat (*Triticum aestivum* L.) to Priming

3.1. Introduction

In saline environments, priming has been found to enhance germination percentage, germination rate, uniformity and growth of several species. For instance, productivity of wheat (*Triticum aestivum* L.) has been improved by soaking seeds in an inorganic salt solution (Afzal *et al*. 2008). Moreover, grain yield and biomass production of two wheat cultivars was increased by using seed priming with $CaCl_2$, KCl and NaCl (Iqbal and Ashraf 2007).

Cultivars chosen

Seeds of two bread wheat (*Triticum aestivum* L.) cultivars were used in this study, namely cv. S-24 (Pakistani cultivar) which is considered a salt and drought tolerant cultivar. Cultivar S-24 grows in Pakistani arid regions which are similar to Libya. The other cultivar was Slambo (Libyan cultivar). This cultivar is considered as new promising variety and was bred to resist drought and salt stresses. Both cultivars can be grown in Libya and were selected for this study to compare them in terms of their salt tolerance.

S-24 Cultivar.

To increase crop productivity in salt stressed environments, a salt-tolerant wheat (*Triticum aestivum* L.) cultivar S-24 (Reg. No. CV-1044; PI 652453) was established through screening and breeding techniques. S-24 was derived from screening and selection of an F_3 population at 24 dS m^{-1} (240 mM) salinity, and it was developed from a cross between cv. LU-26S and cv. Kharchia in 1992–1993 at the Bahauddin Zakariya University, Multan, Pakistan. S-24 is

salt tolerant, maintaining a high K^+: Na^+ ratio in plant tissue, and possesses good agronomic characteristics including grain yield and 1000 kernel weight (TKW) (Ashraf 2008). One year old seeds of cv. S-24 with 98% of seed vigour were used in this study (See raw data in Appendix 1.1).

Slambo Cultivar.

The Libyan cultivar Slambo was obtained from the Libyan Agricultural Research Centre. This cultivar has officially tested for a large scale project in 2006 / 2007 season under optimum condition. The yield obtained by the government was satisfactory. The average productivity rate was 6.83 t ha^{-1} under irrigation condition, and the length of plant was 89 cm, the number of days for grain, spicing and maturity was 44, 92 and 136 respectively. However, its performance under salt stressed conditions has not been investigated. Therefore, its response to salt stress was determined in this study. Two years old seeds of cv. Slambo with 97% of seed vigour were used in this study (See Appendix 1.1).

Owing to scarce information on the responses of cv. S-24 and cv. Slambo to priming treatments, several priming methods were tested. This involved investigating the response of the two cultivars to priming treatments, selecting the best priming treatment for increasing salt tolerance of the two wheat cultivars, and finally the effect of the selected seed priming treatment on the emergence and seedling establishment of the two cultivars.

3.2. Determining the best pre-sowing seed treatment for improving germination of two wheat cultivars under optimum and saline conditions

The results of the primary germination experiments (A1.2) showed that NaCl, $CaCl_2$, KCl and hydropriming were the most effective pre-sowing seed treatments which gave the best

germination in optimum and saline conditions. Therefore, these treatments were applied in this experiment.

This experiment aimed to determine the best pre-sowing seed treatment that enhances the germination percentage, germination rateand the mean germination time of the two wheat cultivars under optimum and saline growing conditions.

3.2.1. Materials and methods

Before starting the experiment, seeds of the two cultivars of wheat were surface sterilized in 1% sodium hypochlorite (NaOCl) solution for 3 min to avoid the invasion of fungi. After this seeds were rinsed using sterilized water and were left to surface dry for 10 min (Afzal *et al.* 2008). The seeds were then subjected to the priming treatments described below.

Halopriming

Three different priming agents (NaCl, $CaCl_2$ and KCl) were used as halopriming treatments. Solutions of 50 mM of each agent were prepared (Afzal *et al.* 2008). Seeds of the two wheat cultivars were soaked in 100 ml of these solutions separately and were put in the growth incubator at 25°C for 17 hours (Blackwell, Sharna, and Riethmuller 2006). After soaking, the treated seeds were washed thoroughly with distilled water and then allowed to surface dry for few minutes (Afzal *et al.*2008).

Hydropriming

Seeds of the two wheat cultivars were soaked in 100 ml of distilled water and were put in the growth incubator at 25°C for 17 hours (Blackwell, Sharna, and Riethmuller 2006). They were then left to surface dry (Afzal *et al.* 2008).

Germination Test

The objective of the germination test was to investigate the effectiveness of pre-sowing treatments on germination capacity and germination rate under optimum and saline conditions for these cultivars. Based on the results obtained, the treatment that can best enhance the germination percentage, germination rate and mean germination time was determined. Twenty primed seeds of each wheat cultivar from different priming treatments and twenty non-primed seeds from each cultivar (as a control) were put in separate 9 cm diameter Petri dishes containing two Whatman No. 1 filter papers (Ghiyasi *et al.* 2008; Salehzade *et al.* 2009) moistened with 10 ml of 0, 100, 200 or 300 mM NaCl to create saline conditions (Afzal *et al.* 2008).

Hydropriming, halopriming and osmopriming contain water. Thus the improvement in germination in seeds subjected to halopriming or osmopriming can be due to salts used in priming treatment or can be due to water. Therefore, hydropriming in addition to its use as a priming technique was also used for comparison with other priming treatments to determine the cause of the enhancement. Moreover, dry seeds (untreated seeds) were also used to find if the priming treatments had any effect on the seed germination or not.

The Petri dishes were covered with lids and closed with parafilm to prevent evaporation, so minimizing the changes in concentration of the solutions (Jamil and Rha 2007). Petri dishes were placed in a growth incubator at 25°C. The experiment was arranged in a completely randomized design (CRD).

5 priming agents including control × 2 wheat cultivars × 4 NaCl concentrations = 40 treatments × 3 replicates = 120 Petri dishes

Seeds were considered germinated when the radicle had reached 2 mm in length (Akbari, Sanavy, and Yousefzadeh 2007; Salehzade *et al.* 2009). Germinated seeds were counted every 24 h for 10 days (Rahman *et al.* 2008). Germinated seeds were discarded after

counting, enabling not only the germination percentage but also the rate of germination and the mean germination time to be determined for each treatment.

Germination Percentage (%)

The final germination percentage was recorded at the end of the experiment. It was calculated as the number of seeds which germinated within 10 days as a proportion of the number of seeds sown in each treatment, expressed as a percentage (Othman *et al.* 2006).

$$\text{Final germination percentage} = (\text{No germinated seed} / \text{Total seeds sown}) \times 100$$

Germination Rate (GR)

The germination rate was calculated based on the time to achieve 50% germination of seeds. The following formula was used:

$$\text{Germination rate} = 1/ T_{50}.$$

Where T_{50} = the time (day) to obtain 50% of final germinated seeds.

Mean germination time (MGT)

The mean germination time (day) was calculated per treatment according to the equation of Ghiyasi *et al.* (2008):-

$$MGT = \sum Dn / \sum n$$

Where:

n = the number of seeds, which germinated on day D.

D= the number of days counted from the beginning of germination.

Data were subjected to three way ANOVA. Tukey's test at $p \leq 0.05$ was used for separation of treatment means. The final germination percentage data was arcsine transformed before analysis.

3.2.2. Results

Germination Percentage (G%)

Three way ANOVA indicated that both priming and NaCl concentration had a significant effect on germination percentage ($p < 0.05$) (Table 3.1). Furthermore, the effect of the interaction between cultivar and NaCl concentration, and priming and NaCl concentration was also significant ($p<0.05$).

Table 3.1.The significance of interactions between treatments using ANOVA for G%.

Treatment Combination	Significant or not	p
Cultivar	NS	0.50
Priming	S	<0.001
NaCl concentration	S	<0.001
Cultivar*Priming	NS	0.06
Cultivar*NaCl Concentration	S	<0.001
Priming* NaCl Concentration	S	<0.001
Cultivar*Priming* NaCl Concentration	NS	0.67

Salinity had a negative effect on the germination percentage (Table 3.2). The germination percentage ranged from 96.7 - 87.5% in unstressed condition to 70.8 - 24.2% at 300 mM. With cv. Slambo, the first significant decrease in germination percentage was recorded at 100 mM in unprimed seeds and at 200 mM with hydropriming, KCl and NaCl but only at 300 mM with $CaCl_2$. With cv. S-24, the first significant decrease was recorded at 200 mM for unprimied seeds and seeds primed with KCl, while it did not occur until 300 mM with hydropriming, NaCl, and $CaCl_2$.

Table 3.2. Effect of different salinity levels on germination percentage (G%) of primed (H_2O, $CaCl_2$, KCl and NaCl) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, range in brackets, n = 6).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	UP	96^{ab}(90-100)	$82^{cdefghi}$(75-90)	59^{ijklmn}(50-70)	29^{op}(20-35)
	H_2O	91^{abcde}(85-100)	94^{abcd}(90-100)	65^{hijklm}(55-75)	29^{op}(15-40)
	KCl	97^{a}(90-100)	94^{abcd}(90-100)	$80^{defghij}$(70-85)	50^{klmno}(45-60)
	$CaCl_2$	96^{ab}(85-100)	95^{abc}(85-100)	89^{abcdef}(80-95)	$65^{hijklmn}$(45-80)
	NaCl	93^{abcd}(85-100)	90^{abcde}(80-100)	$73^{efghijk}$(65-85)	24^{p}(15-35)
S-24	UP	95^{abc}(90-100)	$85^{bcdefgh}$(80-90)	$68^{ghijklm}$(65-75)	35^{nop}(30-55)
	H_2O	$87^{abcdefg}$(75-100)	$85^{bcdefgh}$(80-95)	$70^{fghijkl}$(65-80)	43^{mnop}(35-50)
	KCl	95^{abc}(85-100)	$87^{abcdefg}$(80-95)	$80^{defghij}$(65-85)	56^{jklmn}(45-65)
	$CaCl_2$	95^{abc}(90-100)	90^{abcde}(80-100)	90^{abcdef}(80-100)	$70^{fghijkl}$(60-80)
	NaCl	91^{abcde}(80-95)	$88^{abcdefg}$(85-100)	$86^{abcdefgh}$(80-100)	38^{nop}(25-45)

In both wheat cultivars, as compared to unprimed seeds, at 0 and 100 mM of NaCl, the result showed that there was no significant effect of priming treatments on the germination percentage (Table 3.2). However, at 200 mM seeds treated with $CaCl_2$ had a significantly higher germination percentage than unprimed seeds in both cv. Slambo and cv. S-24. Furthermore, at 300 mM, primed seeds with $CaCl_2$ also had a significant higher germination percentage than unprimed seeds of both cv. Slambo and cv. S-24. No other priming treatment differed significantly from unprimed seeds. There was no significant difference between cultivars for all treatments and under all NaCl concentrations.

Germination Rate (GR)

Three way ANOVA showed that all the factors and their combinations had a significant effect on germination rate ($p < 0.05$) except cultivar and the overall interaction where the effect was not significant ($p > 0.05$) (Table 3.3).

Table 3.3.The significance of interactions between treatments using ANOVA for GR.

Treatment Combination	Significant or not	P
Cultivar	NS	0.11
Priming	S	<0.001
NaCl concentration	S	<0.001
Cultivar*Priming	S	0.01
Cultivar*NaCl Concentration	S	<0.001
Priming* NaCl Concentration	S	<0.001
Cultivar*Priming* NaCl Concentration	NS	0.12

The effect of NaCl stress on GR is shown in Table 3.4. The increase in NaCl concentration led to a decrease in germination rate across all priming treatments. GR ranged from 0.55 – 0.64 at 0 mM to 0.21 – 0.39 at 300 mM. With cv. Slambo, a significant reduction relative to unstressed conditions was recorded at 200 mM in all priming treatments except in hydropriming where the significant reduction occurred at 100 mM. Conversely with cv. S-24, $CaCl_2$ was the only treatment that recorded a significant reduction in GR relative to controls at 200 mM. The significant reduction was at 100 mM in all other treatments.

Table 3.4. Effect of different salinity levels on germination rate (GR) ($1/T_{50}$) of primed (H_2O, $CaCl_2$, KCl and NaCl) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, range in brackets, n = 6).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	UP	0.61^{abcd}(0.6-0.64)	0.54^{cdefgh}(0.45-0.57)	0.31^{nopq}(0.30-0.37)	0.23^{r}(0.20-0.28)
	H_2O	0.63^{ab}(0.60-0.65)	0.51^{efghi}(0.42-0.54)	0.37^{mn}(0.34-0.40)	0.21^{r}(0.21-0.22)
	KCl	0.64^{a}(0.62-0.65)	$0.56^{abcdefg}$(0.52-0.57)	0.34^{mnop}(0.31-0.38)	0.27^{pqr}(0.25-0.28)
	$CaCl_2$	0.62^{abc}(0.54-0.65)	0.61^{abcd}(0.57-0.62)	0.41^{jklm}(0.38-0.42)	0.31^{nopq}(0.29-0.36)
	NaCl	0.61^{abcd}(0.59-0.63)	0.54^{cdefgh}(0.46-0.60)	0.40^{klmn}(0.38-0.50)	0.25^{qr}(0.23-0.30)
S-24	UP	$0.55^{bcdefgh}$(0.48-0.57)	0.41^{jklm}(0.38-0.44)	0.36^{mno}(0.34-0.37)	0.25^{qr}(0.23-0.26)
	H_2O	0.59^{abcde}(0.55-0.61)	0.47^{hijkl}(0.43-0.51)	0.42^{ijklm}(0.40-0.47)	0.28^{opqr}(0.26-0.30)
	KCl	0.61^{abcd}(0.58-0.62)	0.48^{ghijk}(0.42-0.50)	0.41^{jklm}(0.35-0.55)	0.31^{nopq}(0.30-0.33)
	$CaCl_2$	0.57^{abcdef}(0.54-0.61)	0.53^{defgh}(0.52-0.55)	0.48^{ghijk}(0.43-0.54)	0.39^{lmn}(0.37-0.42)
	NaCl	0.60^{abcde}(0.58-0.62)	0.49^{fghij}(0.45-0.52)	0.38^{mn}(0.33-0.41)	0.28^{opqr}(0.24-0.32)

With cv. Slambo, priming with $CaCl_2$ increased GR significantly compared to unprimed seeds at 200 and 300 mM of NaCl, while it was at 100, 200 and 300 mM with cv. S-24.

The effect of cultivar on GR was recorded in one case, with unprimed seeds at 100 mM, where germination rate in cv. Slambo was significantly higher than in cv. S-24.

Mean Germination Time (MGT)

Three way ANOVA indicated that the effect of all the factors and their combinations on the MGT was significant ($p < 0.05$), with the exception of cultivar (Table 3.5).

Table 3.5.The significance of interactions between treatments using ANOVA for MGT.

Treatment Combination	Significant or not	P
Cultivar	NS	0.18
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	0.02

Table.3.6. Effect of different salinity levels on mean germination time (MGT) (day) of primed (H_2O, $CaCl_2$, KCl and NaCl) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values,standard errors in brackets, n = 6).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	UP	2.2^{op}(0.0)	$2.6^{ijklmno}$(0.0)	3.6^{def}(0.1)	5.1^{a}(0.2)
	H_2O	2.2^{op}(0.0)	2.9^{ghijkl}(0.0)	3.3^{efgh}(0.0)	5.2^{a}(0.1)
	KCl	2.1^{p}(0.0)	$2.7^{ijklmno}$(0.0)	3.6^{def}(0.0)	4.3^{bc}(0.0)
	$CaCl_2$	2.2^{op}(0.1)	2.3^{mnop}(0.0)	3.1^{efghi}(0.0)	4.0^{cd}(0.1)
	NaCl	2.3^{nop}(0.0)	2.9^{ghijkl}(0.1)	3.4^{efg}(0.1)	4.5^{bc}(0.1)
S-24	UP	$2.6^{ijklmnop}$(0.0)	3.2^{efgh}(0.0)	3.6^{def}(0.0)	4.7^{ab}(0.0)
	H_2O	2.4^{lmnop}(0.0)	3.0^{ghijk}(0.1)	3.1^{fghij}(0.0)	4.3^{bc}(0.1)
	KCl	2.2^{op}(0.1)	$2.9^{hijklmn}$(0.1)	3.4^{efg}(0.1)	3.6^{de}(0.0)
	$CaCl_2$	2.5^{klmnop}(0.0)	$2.6^{ijklmno}$(0.0)	3.0^{ghijk}(0.0)	3.4^{efg}(0.0)
	NaCl	$2.5^{jklmnop}$(0.0)	$2.9^{ghijklm}$(0.1)	3.3^{efgh}(0.0)	4.5^{bc}(0.0)

Salinity negatively affected the MGT. MGT increased significantly with the increase in NaCl concentration (Table 3.6). In both wheat cultivars the first significant increase in MGT was recorded at 100 mM in all treatments except in unprimed seeds and $CaCl_2$ where the

significant increase was at 200 mM with cv. Slambo, and at 200 mM in NaCl and at 300 mM in $CaCl_2$ with cv. S-24.

The effect of priming treatment on the MGT was also significant in some cases. With cv. Slambo at 300 mM, the lowest MGT was recorded in seeds treated with $CaCl_2$ followed by KCl and NaCl, all of which were significantly lower than the control. However, none of these three priming treatments showed any significant difference from each other. With cv. S-24at 100 and 200 mM, the minimum MGT was achieved in seeds primed with $CaCl_2$, and this was the only priming treatment that was significantly lower than the control. At 300 mM, the lowest MGT was also achieved in seeds primed with $CaCl_2$ followed by KCl, both of which were significantly lower than control but neither of these showed any significant difference from each other.

The effect of cultivar was not clear except with unprimed seeds at 100 mM and with hydropriming and priming with KCl and $CaCl_2$ at 300 mM where MGT for cv. S-24 was significantly greater than for cv. Slambo.

Table 3.7.Summary of the experiment of the effect of seed priming on seed germination.

Cultivar	Treatment	NaCl	G%	GR	MGT
Slambo	H_2O	**0**			
		100			
		200			
		300			
	KCl	**0**			
		100			
		200			
		300			✓
	$CaCl_2$	**0**			
		100			
		200	✓	✓	
		300	✓	✓	✓
	NaCl	**0**			
		100			
		200			
		300			✓
S-24	H_2O	**0**			
		100			
		200			
		300			
	KCl	**0**			
		100			
		200			
		300			✓
	$CaCl_2$	**0**			
		100		✓	✓
		200	✓	✓	✓
		300	✓	✓	✓
	NaCl	**0**			
		100			
		200			
		300			

G% = germination percentage.

GR = germination rate.

MGT = mean germination time.

✓ = significant positivecompared to control (Unprimed)

3.2.3. Discussion

The low wheat yield in salt-affected soils is often attributed to low seed germination, emergence and poor seedling establishment (Abro, Mahar, and Mirbahar 2009). Seed germination is the phase most sensitive to salt stress in many crops (Dhanapackiam and Ilyas

2010). Seed priming has been successfully demonstrated to improve germination and emergence in seeds of many crops (Kaya *et al*. 2006; Zhao, Zhong, and Zhong 2009; Moosavi *et al*. 2009; Golezani *et al*. 2010) such as wheat (Harris 2004; Afzal *et al*. 2008; Ghiyasi *et al*. 2008; Salehzade *et al*. 2009), maize (Harris *et al*. 2007; Foti *et al*. 2008), barley (Rashid *et al*. 2006) and sunflower (Bajehbaj 2010).

Germination Percentage (G%)

Many studies on the effect of salt stress on seed germination indicate that during the germination phase the seeds are sensitive to salt stress. The present results showed that the germination percentage was significantly decreased with the increase in salinity by reducing the final proportion of germinated seeds of both wheat cultivars, thus confirming the results of Ashraf, Ashraf and Ali (2010) with wheat. This decrease in germination percentage is probably due either to the increase in osmotic pressure or due to the toxicity of Na^+ ions (Rahman *et al.* 2008). Homayoun (2011) found that germination was directly related to the amount of water absorbed and the delay in germination due to the salt concentration in the root zone.

Pre-sowing seed treatments with solutions of different inorganic salts have been found to improve germination percentage under stressed conditions (Basra *et al*. 2005; Afzal *et al*. 2008).

In the present study, compared to unprimed treatments, priming with $CaCl_2$ was the most successful treatment that enhanced the final germination percentage in both wheat cultivars under saline conditions. This increase in germination percentage is in agreement with the results reported by Afzal *et al*. (2006a), Rafiq *et al*. (2006) and Afzal *et al*. (2008) with wheat. Farooq *et al*. (2010a) also found that seed priming with $CaCl_2$ was the most successful treatment in increasing the germination percentage with rice seeds. Ashraf and Rauf (2001)

reported that pre-sowing seed treatment with $CaCl_2$ was more effective because the seeds primed with this salt had significantly higher final germination percentage. Afzal *et al*. (2008) pointed out that a pre-sowing seed treatment with calcium salts improved germination under salt stress possibly due to the effect of calcium on membranes. Also Rafiq *et al*. (2006) indicated that calcium is recognized to have an antagonistic influence on the absorption of sodium in plant metabolism, and thus protects plants from the adverse effects of NaCl.

As compared to unprimed seeds, all the other pre-sowing treatments (H_2O, KCl, and NaCl) did not significantly increase the germination percentage of both wheat cultivars under distilled water and saline conditions.

Halopriming with KCl failed to increase germination percentage significantly in the two wheat cultivars under saline and non-saline conditions as compared to unprimed treatment. This finding is in agreement with Yari, Aghaalikani, and Khazaei (2010) with wheat (*Triticum aestivum* L.). Moreover, hydropriming also did not enhance the germination percentage significantly of both wheat cultivars under either saline or non-saline conditions. The failure of hydropriming to increase the final germination percentage is supported by Afzal *et al*. (2006a). However, there is published research demonstrating the effectiveness of hydropriming on germination in different plant species under distilled water and saline conditions. Saglam *et al*. (2010) reported that hydropriming increased the germination percentage of lentil (*Lens culinaris* Medik) under saline and non-saline conditions. The same results have been found by Basra *et al*. (2005) with wheat, and Janmohammadi, Dezfuli, and sharifzadeh (2008) with maize. Finally, priming with NaCl failed to significantly increase the germination percentage of both wheat cultivars compared with the control. This may result from the propensity of seeds primed with NaCl to take up more Na^+ and / or Cl^- from the salt solution, which leads to an increase in the concentration of Na^+ in plant tissue causing

toxicity. This finding is in accordance with the results of Basra *et al*. (2005), Afzal *et al*. (2007b), and Afzal *et al*. (2008) with wheat.

Germination Rate (GR)

The present results showed that salinity had a negative effect on germination rate. The germination rate was significantly decreased with the increase in salt concentration. Of all the pre-sowing seed treatments, priming with $CaCl_2$ was the most successful seed priming treatment that increased the germination rate in both wheat cultivars under saline conditions. The accelerated germination rate due to priming under salt stress may be due to an increase in water uptake rate to achieve the important moisture content required for germination (Saglam *et al*. 2010) or could be due to the acceleration of the rate of the cell division as calcium plays an important role in cell wall structure and cell division (Patade, Bhargava, and Suprasanna 2009).

All the remaining pre-sowing treatments failed to increase the germination rate significantly in both wheat cultivars under either non-saline or saline conditions. This result is in line with the findings of Afzal *et al*. (2006a) and Afzal *et al*. (2008) in wheat (*Triticum aestivum* L.).

Mean Germination Time (MGT)

The two most important pre-requisites to enhance yield and quality in annual crops are quick and uniform germination and emergence of seedlings in the field (Golezani *et al*. 2010a).

It has been reported that MGT is affected by salinity (Patade, Bhargava, and Suprasanna 2009; Bajehbaj 2010). In this study, the effect of salinity was clearly observed. MGT increased significantly as salt concentration increased in both wheat cultivars. Farooq *et al*. (2010a) reported that pre-sowing seed treatments produced quick and uniform emergence,

and increased the yield of field crops under a variety of environmental conditions such as soil salinity.

Compared to unprimed treatment, priming with $CaCl_2$, KCl and NaCl resulted in the significantly shortest MGT at 300 mM with cv. Slambo, while with cv. S-24, $CaCl_2$ at 100, 200 and 300 mM significantly reduced the MGT followed by KCl at 300 mM. This reduction of the MGT is probably due to the increased water absorption rate and earlier initiation of metabolic processes (Saglam *et al*. 2010). These results are in accordance with Afzal *et al*. (2006a) and Afzal *et al*. (2008) who reported that seeds of wheat subjected to priming with 50 mM $CaCl_2$ were significantly decreased MGT compared to control.

From the results, it can also be confirmed that $CaCl_2$ was the most successful pre-sowing seed treatment as $CaCl_2$ improved the G%, GR, and MGT.

3.3. Determination of the effect of the selected pre-sowing treatment on the emergence of wheat cultivars under salt stress

The results of the previous experiment showed that halopriming with $CaCl_2$ was the best priming treatment that improved all germination parameters of both wheat cultivars under saline conditions in the laboratory experiment. Therefore, this priming agent was selected for this experiment.

This experiment aimed to investigate the effectiveness of the selected pre-sowing seed treatment on the establishment of wheat cultivars in the greenhouse.

3.3.1. Materials and methods

Prior to sowing, seeds of the two wheat cultivars were primed with 50 mM of $CaCl_2$, the selected priming agent. Twenty primed and non-primed seeds from each wheat cultivar were sown in 13 cm pots filled with 1 kg of horticultural grade washed and lime-free silver sand.

This sand is nutrient-poor and was chosen to reflect the Libyan soil as most Libyan soils are sandy and suffer from a shortage of nutrients. A commercial horticultural sand was also used to reduce the potential variability in using Libyan sand. In order to impose salt stress, four concentrations of NaCl (0, 100, 200 and 300 mM) were applied. Pots were irrigated up to the field capacity once a week and when needed, with NaCl solutions in addition to distilled water as a control. The experiment was arranged in a completely randomized design (CRD).

2 seed treatments (primed and unprimed as control) × 2 wheat cultivars × 4 NaCl concentrations = 16 treatments × 5 replicates = 80 pots

The seedlings were harvested after five weeks of sowing before the stem extension stage starts where the first node and flag leaf are just visible (White and Edwards 2008). The E%, ER and MET were recorded, dry and fresh weight of roots and shoots and the length of shoots and roots were also measured.

Emergence Percentage (%)

The final E% was recorded at the end of the experiment. It was calculated as the number of seeds which emerged as a proportion of the number of seeds sown in each treatment, expressed as a percentage (Othman *et al.* 2006).

$$\text{Final emergence percentage} = (\text{No emerged seed} / \text{Total seeds sown}) \times 100$$

Emergence Rate (ER)

Based on the number of emerged seeds recorded every day, emergence rate per potwas determined according to the following formula:

$$\text{Emergence rate} = 1/ T_{50}.$$

Where T_{50} = the time to obtain 50% of emerged seeds.

Mean Emergence Time (MET)

The mean emergence time per treatment was calculated according to the equation of Ghiyasi *et al.* (2008):-

$$MET = \sum Dn / \sum n$$

Where:

n = the number of seeds, which emerged on day D.

D= the number of days counted from the beginning of emergence.

Shoot and Root Length

At the end of the experiment, the length of shoots and roots was determined**.** The length of shoots and roots was measured for eachpot.

Fresh Weight of Shoots and Roots

Five weeks after sowing, the seedlings were collected, washed in distilled water, and then dried with filter paper. Seedlings were separated into shoots and roots. Fresh weight of both shoots and roots was recorded for each plant using an electronic balance and then were calculated as a mean for each pot.

Dry Weight of Shoots and Roots

Shoots and roots for each replicate were put in marked aluminium trays and were dried using an electric oven at 80°C for 48 h (Akbari, Sanavy, and Yousefzadeh 2007). Dry weight was determined using an electronic balance and averaged for each pot.

The emergence percentage was arcsine transformed prior to subjection to statistical analysis. The data were subjected to three-way ANOVA. Means were separated by Tukey's test at $p \leq 0.05$.

3.3.2. Results

The Effect of Priming on Emergence of the Wheat Cultivars

Salinity had negative effects onall growth parameters. Emergence percentage (E%), emergence rate (ER), mean emergence time (MET), shoot and root length, fresh weight of shoots and roots, and dry weight of shoots and roots were all negatively affected as the salinity level increased.

Emergence Percentage (E%)

Three way ANOVA showed that cultivar, priming and NaCl concentration had a significant effect on emergence percentage ($p < 0.05$). Moreover, the interaction between priming and NaCl concentration was also significant ($p < 0.05$) (Table 3.8).

Table 3.8. The significance of interactions between treatments using ANOVA for E%.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.81
Cultivar*NaCl Concentration	NS	0.10
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.71

The increase in NaCl concentration had a negative effect on the E% in both wheat cultivars. The E% ranged from 91 - 94% at 0 mM to 5 – 39% at 200 mM. A significant decrease in E% was recorded at 200 mM in primed seeds and at 100 mM in unprimed seeds in both cultivars.

The results (Table 3.9) showed that with distilled water there was no significant difference between $CaCl_2$ primed and un-primed treatments for both wheat cultivars. However, at 100 and 200 mM of NaCl the E% was significantly greater in primed seeds than in unprimed seeds of both cultivars. At 300 mM there was no emergence recorded for seeds of either wheat cultivar.

Table. 3.9. Effect of different salinity levels on emergence percentage (E%) of primed ($CaCl_2$) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, range in brackets,*= no emergence, n = 5)

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	$CaCl_2$	93^{a}(85-100)	90^{ab}(85-95)	19^{e}(10-25)	*
	UP	91^{ab}(85-100)	69^{c}(65-85)	5^{f}(05-10)	*
S-24	$CaCl_2$	94^{a}(85-100)	97^{a}(95-100)	39^{d}(30-45)	*
	UP	93^{a}(85-100)	77^{bc}(65-80)	15^{ef}(10-20)	*

There was no effect of cultivar on emergence except at 200 mM where emergence percentage of cv. S-24 primed seeds was significantly greater than of cv. Slambo primed seeds.

Emergence Rate (ER)

Three way ANOVA indicated that all factors and their combinations had a significant effect ($p < 0.05$) on the emergence rate except the interaction between cultivar and priming (Table 3.10).

Table 3.10.Testing the significance of interactions between treatments using ANOVA for ER.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.82
Cultivar*NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	<0.01

Salinity clearly decreased the ER in both cultivars. The increase in NaCl concentration caused a significant decrease in ER in both wheat cultivars under all salinity levels, whether seeds were primed or not (Table 3.11). The ER ranged from 0.22 - 0.25 at 0 mM to 0.02 - 0.1 at 300 mM of NaCl. The significant reduction in ER occurred at 100 and 200 mM with primed and unprimed seeds of both cultivars. Table 3.11 showed that there was no effect of priming on the ER under unstressed conditions in both wheat cultivars.

Table 3.11. Effect of different salinity levels on emergence rate (ER) ($1/T_{50}$) of primed ($CaCl_2$) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, range in brackets,$*$= no emergence, n = 5)

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	$CaCl_2$	0.23^{ab}(0.18-0.25)	0.17^{c}(0.14-0.17)	0.09^{ef}(0.06-0.11)	*
	UP	0.22^{b}(0.19-0.23)	0.15^{cd}(0.13-0.17)	0.02^{g}(0.04-0.04)	*
S-24	$CaCl_2$	0.25^{a}(0.23-0.27)	0.18^{c}(0.15-0.19)	0.10^{e}(0.08-0.11)	*
	UP	0.23^{ab}(0.21-0.25)	0.13^{de}(0.11-0.14)	0.06^{f}(0.06-0.07)	*

However, at 100 mM NaCl, primed seeds of cv. S-24 were able to increase their ER significantly compared to unprimed seeds. Moreover, at 200 mM, priming significantly increased the emergence ratein both cultivars. No emergence was recorded at 300 mM in both wheat cultivars. The effect of cultivar on ER was found at 200 mM in unprimed seeds where emergence rate of cv. S-24 was significantly higher than in cv. Slambo.

Mean Emergence Time (MET)

Three way ANOVA showed that all the relationships had no significant effect ($p > 0.05$) on the mean emergence time except priming and NaCl concentration where the effect was significant ($p < 0.05$) (Table 3.12).

Table 3.12. The significance of interactions between treatments using ANOVA for MET.

Treatment Combination	Significant or not	P
Cultivar	NS	0.91
Priming	S	0.04
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.67
Cultivar*NaCl Concentration	NS	0.98
Priming* NaCl Concentration	NS	0.21
Cultivar*Priming* NaCl Concentration	NS	0.95

The increase of NaCl level had a negative effect on the MET (Table 3.13). MET ranged from 4.7 - 5.6 days at 0 mM to 11.1 - 15.8 days at 200 mM. The results showed that the first significant increase in MET as affected by the increase of NaCl concentrations occurred only in unprimed seeds at 200 mM, while there was no significant increase in MET in primed seeds of either cultivar. Furthermore, the effect of cultivar on the MET was also not significant.

Table 3.13. Effect of different salinity levels on mean emergence time (MET) (day) of primed ($CaCl_2$) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets,$*$= no emergence, n = 5)

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	$CaCl_2$	$5.1^{c}(0.2)$	$7.0^{abc}(0.3)$	$11.1^{abc}(0.8)$	*
	UP	$5.6^{c}(0.2)$	$7.7^{abc}(0.2)$	$15.1^{ab}(0.1)$	*
S-24	$CaCl_2$	$4.7^{c}(0.1)$	$6.6^{bc}(0.3)$	$10.2^{abc}(0.2)$	*
	UP	$5.3^{c}(0.1)$	$8.3^{abc}(0.2)$	$15.8^{a}(0.3)$	*

Shoot and Root Length

Shoot Length

Three way ANOVA indicated that the individual factors had a significant effect on shoot length ($p < 0.05$) (Table 3.14). Furthermore, the interaction betweencultivar and priming,

cultivar and NaCl concentration, and priming and NaCl concentration were also significant ($p > 0.05$).

Table 3.14.The significance of interactions between treatments using ANOVA for shoot length.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.11

The increase in NaCl level led to decrease in shoot length. Shoot length ranged from 18.6 to 33.8 cm at 0 mM to 0.8 to 6.4 cm at 200 mM. In both cultivars shoot length decreased significantly under all NaCl concentrations whether seeds were primed or not (Table 3.15).

Table 3.15. Effect of different salinity levels on shoot length (cm plant^{-1}) of primed ($CaCl_2$) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets,$*$= no emergence, n = 5)

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	$CaCl_2$	26.6^{b}(0.7)	18.9^{d}(0.5)	3.6^{fg}(0.4)	*
	UP	18.6^{d}(0.5)	12.9^{e}(0.8)	0.8^{h}(0.3)	*
S-24	$CaCl_2$	33.8^{a}(0.7)	24.3^{bc}(0.2)	6.4^{f}(0.2)	*
	UP	22.6^{c}(0.8)	13.7^{e}(0.3)	2.4^{gh}(0.3)	*

Priming with $CaCl_2$ increased shoot length, such that at 0, 100 and 200 mM of NaCl, shoot length was significantly greater in primed seeds than in unprimed seeds of both wheat cultivars. The effect of cultivar was recorded in some cases especially at 0 mM where shoot length of cv. S-24 was significantly greater than of cv. Slambo in primed and unprimed seeds

and at 100 mM where shoot length was greater in primed seeds of cv. S-24 than in cv. Slambo.

Root Length

Three way ANOVA indicated that cultivar, priming, NaCl concentration, and the interaction between priming and NaCl concentrationhad a significant effect ($p < 0.05$) on root length of both wheat cultivars **(**Table 3.16).

Table 3.16.The significance of interactions between treatments using ANOVA for root length.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.23
Cultivar*NaCl Concentration	NS	0.27
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.13

Salinity had a negative effect on root length. Root length of both cultivars was reduced significantly with increase in NaCl concentration in both primed and unprimed seeds of both wheat cultivars (Table 3.17). Root length ranged from 18.1 - 27.3 cm at 0 mM to just 0.8 - 6.3 cm at 200 mM.

Table 3.17. Effect of different salinity levels on root length (cm plant^{-1}) of primed ($CaCl_2$) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets,$*$= no emergence, n = 5)

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	$CaCl_2$	22.9^{b}(1.0)	10.2^{de}(0.4)	4.1^{gh}(0.3)	*
	UP	18.1^{c}(0.4)	6.1^{fg}(0.4)	0.8^{i}(0.3)	*
S-24	$CaCl_2$	27.3^{a}(0.7)	12.0^{d}(0.5)	6.3^{fg}(0.2)	*
	UP	19.8^{c}(0.9)	8.5^{ef}(0.4)	2.5^{hi}(0.4)	*

Priming with $CaCl_2$ increased root length compared to controls (Table 3.17). The root length obtained from primed seeds was significantly greater than in unprimed seeds at all NaCl concentration in both cultivars.

The effect of cultivar on root length was recorded only in one case, at 0 mM where root length of cv. S-24 primed seeds was significantly higher than root length of primed seeds of cv. Slambo.

Fresh Weight of Shoots and Roots

Fresh Weight of Shoots

Three way ANOVA indicated that cultivar, priming and NaCl concentration had significant effect on shoot fresh weight ($p < 0.05$) (Table 3.18). Furthermore, the effect of the interaction between cultivar and NaCl concentrations, and priming and NaCl concentrations was also significant ($p < 0.05$).

Table 3.18.The significance of interactions between treatments using ANOVA for shoot fresh weight.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.57
Cultivar*NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.47

The result showed that the increase in NaCl concentration decreased shoot fresh weight (Table 3.19). Shoot fresh weight ranged from 2.8 - 4.4 g at 0 mM to 0.01 - 1.2 g at 200 mM. This decrease was significant under all NaCl concentrations and whether seeds were primed or not.

Table 3.19. Effect of different salinity levels on shoot fresh weight (g plant^{-1}) of primed ($CaCl_2$) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, * = no emergence, n = 5).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	$CaCl_2$	3.7^{ab}(0.2)	2.0^{d}(0.1)	0.9^{e}(0.0)	*
	UP	2.8^{c}(0.1)	0.9^{e}(0.0)	0.1^{f}(0.0)	*
S-24	$CaCl_2$	4.4^{a}(0.2)	2.6^{cd}(0.0)	1.2^{e}(0.1)	*
	UP	3.6^{b}(0.2)	1.1^{e}(0.1)	0.3^{f}(0.0)	*

Table 3.19. demonstrated that at 0, 100 and 200 mM NaCl, shoot fresh weight obtained from primed seeds was significantly higher than that from unprimed seeds (control) in both cultivars. Furthermore, there was no significant effect of cultivar on shoot fresh weight except with unprimed seeds at 0 mM where shoot fresh weight of cv. S-24 was significantly higher than shoot fresh weight of cv. Slambo.

Fresh Weight of Roots

Three way ANOVA showed that all the factors and their combinations had a significant effect ($p < 0.05$) on the root fresh weight except the interaction between cultivar and priming, and the overall interaction where the effect was not significant ($p > 0.05$) (Table 3.20).

Table 3.20. The significance of interactions between treatments using ANOVA for root fresh weight.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.99
Cultivar*NaCl Concentration	S	0.02
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.99

Root fresh weight was reduced significantly by the increase in salt concentration (Table 3.21) across all NaCl concentrations in primed and unprimed seeds of both wheat cultivars. The only exception was unprimed seeds of cv. Slambo which showed no significant decrease in root fresh weight as NaCl concentration increased from 100 to 200 mM. Root fresh weight ranged from 3.9 - 6.5 g at 0 mM to 0.1 - 0.9 g at 200 mM.

Table 3.21. Effect of different salinity levels on root fresh weight (g plant^{-1}) of primed ($CaCl_2$) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, * = no emergence, n = 5).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	$CaCl_2$	6.3^{a}(0.5)	3.1^{bc}(0.2)	0.6^{e}(0.1)	*
	UP	3.9^{b}(0.2)	0.8^{de}(0.0)	0.1^{e}(0.1)	*
S-24	$CaCl_2$	6.5^{a}(0.4)	4.4^{b}(0.3)	0.9^{de}(0.2)	*
	UP	4.1^{b}(0.1)	2.0^{cd}(0.2)	0.5^{e}(0.1)	*

Priming with $CaCl_2$ significantly increased root fresh weight in both cultivars at 0 and 100 mM of NaCl but this increase was not significant at 200 mM. Moreover, there was no effect of cultivar on the root fresh weight under all salt levels.

Dry Weight of Shoots and Roots

Dry Weight of Shoots

Three way ANOVA demonstrated that all individual factors had a significant ($p < 0.05$) effect on the dry weight of shoots (Table 3.22). Furthermore, the effect of the interaction between cultivar and NaCl concentration was also significant ($p < 0.05$).

Table 3.22. The significance of interactions between treatments using ANOVA for shoot dry weight.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.37
Cultivar*NaCl Concentration	S	<0.01
Priming* NaCl Concentration	NS	0.12
Cultivar*Priming* NaCl Concentration	NS	0.52

Shoot dry weight was reduced significantly as salt concentration increased in both wheat cultivars (Table 3.23). Shoot dry weight ranged from 0.6 - 1.2 g at 0 mM to 0.015 - 0.3 g at 200 mM. The effect of salinity on shoot dry weight was significant under all NaCl concentrations whether seeds were primed or not. The only exception was with unprimed seeds of cv. Slambo as NaCl concentration increased from 100 to 200 mm.

Table 3.23. Effect of different salinity levels on shoot dry weight (g plant^{-1}) of primed ($CaCl_2$) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, * = no emergence, n = 5).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	$CaCl_2$	$0.9^{b}(0.1)$	$0.4^{c}(0.3)$	$0.2^{d}(0.1)$	*
	UP	$0.6^{c}(0.0)$	$0.1^{de}(0.0)$	$0.01^{e}(0.1)$	*
S-24	$CaCl_2$	$1.2^{a}(0.1)$	$0.5^{c}(0.0)$	$0.3^{d}(0.4)$	*
	UP	$1.0^{b}(0.1)$	$0.2^{d}(0.4)$	$0.04^{e}(0.0)$	*

The effect of priming treatment on the shoot dry weight was recorded in both cultivars (Table 3.23). Shoot dry weight of seedlings from primed seeds was significantly higher than seedlings from unprimed seeds at 0, 100, and 200 mM NaCl.

The effect of cultivar on shoot dry weight was shown in one treatment. In primed and unprimed seeds at 0 mM. In this treatment shoot dry weight of seedlings obtained from cv. S-24 was significantly greater than shoot dry weight of seedlings obtained from cv. Slambo.

Dry Weight of Roots

Three way ANOVA indicated that cultivar, priming and NaCl concentration had a significant effects on root dry weight ($P < 0.05$) (Table 3.24). Furthermore, the effect of the interaction between priming and NaCl concentration was also significant ($P < 0.05$).

Table 3.24. The significance of interactions between treatments using ANOVA for root dry weight.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.36
Cultivar*NaCl Concentration	NS	0.47
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.93

Root dry weight was also negatively affected by the increase in salt concentration (Table 3.25). The root dry weight declined significantly at 200 mM in all the treatments except with primed seeds of cv. Slambo where the significant decrease occurred at 100 mM, and with unprimed seeds of cv. Slambo where there was no significant effect of salt concentration.

Table 3.25. Effect of different salinity levels on shoot dry weight (g plant^{-1}) of primed ($CaCl_2$) and non-primed (UP) seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, * = no emergence, n = 5).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	$CaCl_2$	$1.9^{a}(0.4)$	$1.3^{b}(0.1)$	$0.1^{d}(0.0)$	*
	UP	$0.6^{cd}(0.0)$	$0.2^{cd}(0.1)$	$0.02^{d}(0.0)$	*
S-24	$CaCl_2$	$2.3^{a}(0.2)$	$1.6^{ab}(0.1)$	$0.3^{cd}(0.1)$	*
	UP	$1.0^{bc}(0.1)$	$0.5^{cd}(0.0)$	$0.1^{d}(0.0)$	*

The effect of priming treatment on root dry weight was shown in Table 3.25. In both wheat cultivars, in non-saline conditions and at 100 mM, root dry weight obtained from primed

seeds was significantly greater than that from unprimed seeds. However, there was no effect of priming treatment on root dry weight in both cultivars at 200 mM NaCl. There was also no effect of cultivar on root dry weight.

Table 3.26. Summary of effect of priming with $CaCl_2$ on the emergence and growth of two wheat cultivars.

Cultivar	NaCl	E%	ER	MET	Length		Fresh Weight		Dry Weight	
					S	R	S	R	S	R
Slambo	0				✓	✓	✓	✓	✓	✓
	100	✓			✓	✓	✓	✓	✓	✓
	200	✓	✓		✓	✓	✓		✓	
S-24	0				✓	✓	✓	✓	✓	✓
	100	✓	✓		✓	✓	✓	✓	✓	✓
	200	✓	✓		✓	✓	✓		✓	

G% = germination percentage.
GR= germination rate.
MGT=mean germination time.
S= shoot.
R = root.
✓ = significant positive effect relative to unprimed seeds.

3.3.3. Discussion

The Effect of Priming on Emergence of Wheat Cultivars

In this experiment, E% was significantly reduced as salt concentration increased. This result is in line with Sayar *et al*. (2010a), and Ashraf, Ashraf and Ali (2010) with wheat, and Bajehbaj (2010) with sunflower. ER was also affected by the increase in NaCl level and decreased significantly with the increase of salt concentration in both wheat cultivars. This finding is in accordance with Rahman *et al*. (2008) and Datta *et al*. (2009) with wheat (*Triticum aestivum* L.), and Bybordi and Tabatabaei (2009) with canola (*Brassica napus* L.). Furthermore, MET was increased by salinity. As salt concentrations increased, MET was also

increased significantly in unprimed seeds at 200 mM but not in primed seeds. The negative effect of the increase of NaCl concentration in the growth medium on the E%, ER and MET might be due to the reduction in the availability of water or due to the toxicity of Na^+ ions as a result of the high accumulation of Na^+ in the root zone (Leithy, Gaballah, and Gomaa 2009; Sayar *et al*. 2010b; Eleiwa, Bafeel and Ibrahim 2011).

In this study, priming with $CaCl_2$ improved the final E% and ER under saline stress in both wheat cultivars. This enhancement is in concurrence with Basra *et al*. (2005), Afzal *et al*. (2006a), Rafiq *et al*. (2006), and Afzal *et al*. (2007b) with wheat. Afzal *et al*. (2008) reported that seed priming with 50 mM $CaCl_2$ increased the salt tolerance of two cultivars of wheat (*Triticum aestivum* L.) under 150 mM NaCl. It has been reported that a pre-sowing seed treatment with $CaCl_2$ was the most successful treatment that raised the E% in rice (Farooq *et al*. 2010b). The results also showed that there was no emergence in primed seeds of both cultivars at 300 mM even though the results of the previous laboratory experiment showed that there was germination in primed seeds at the same NaCl concentration. This can be explained by the death of seed radicle due to ion toxicity before it could reach the 2 cm in length needed to reach the surface of the soil.

The enhanced performance of primed seeds is probably due to the effect of Ca^{2+} on the Na^+ ions. Cramer, Epstein, and Lauchli (1990) reported that Ca^{2+} is able to ameliorate the harmful effects of Na^+ under salt-stressed conditions. In addition, Basra *et al*. (2005), Afzal *et al*. (2006a), Afzal *et al*. (2007b), and Farooq *et al*. (2010b) reported that the improvement in emergence as affected by priming might be due to faster metabolic repair during imbibition, and earlier and faster synthesis of DNA, RNA and proteins required for embryo growth. Therefore, this may explain the enhancement of MET in primed seeds but not in unprimed seeds. Moreover, Afzal *et al*. (2007b) suggested that the improvement in emergence in seeds of wheat (*Triticum aestivum* L.) treated with 50 mM $CaCl_2$ under 15 dS $m^{-1}$of salinity is

probably due to the increase in β-amylase activity and the efficiency of mobilizing nutrients from cotyledons to the embryonic axis. Saglam *et al*. (2010) reported that the enhancement in emergence of lentil (*Lens culinaris* Medik) as affected by seed priming is possibly due increased water uptake rate and earlier commencement of metabolic activities. Kaya *et al*. (2006) and Jamil and Rha (2007) reported that priming increases the osmotic pressure of seeds sufficiently to enable water vital for emergence to be absorbed by seeds. Moreover, Patade, Bhargava, and Suprasanna (2009) suggested that the acceleration in the ER is probably explained by the increase in cell division rate in primed seeds and increase in metabolic activities.

The Effect of Priming on the Growth of Wheat Cultivars

The effect of salinity on the shoot and root length, fresh weight of shoots and roots, and dry weight of shoots and roots was very pronounced in this study. All the growth parameters were reduced significantly as the salt concentration was increased in both wheat cultivars. This result is in accordance with Tammam, Alhamd, and Hemeda (2008), Hameed *et al*. (2008), Datta *et al*. (2009) and Kaya *et al*. (2009) with wheat.

This inhibition in growth parameters might be due to the increase of Na^+ and / or Cl^- in the plant tissue leading to the toxic effect as suggested by Naseem *et al*. (2001) and Afzal *et al*. (2006a). Moreover, it has been suggested that the decrease in growth parameters due to salinity may be attributed to the decrease in water potential as affected by the increase in ion accumulation in the rooting zone which leads to a reduction in the absorbed water (Naseem *et al*. 2001). Furthermore, Naeem and Muhammad (2006), and Rahman *et al*. (2008) reported that the decrease in growth parameters is possibly due to the inhibition of cell division and enlargement as affected by NaCl concentration.

The effect of seed priming treatment with 50 mM $CaCl_2$ was pronounced. Priming with $CaCl_2$ was effective in improving growth parameters under salinity stress. The shoot and root length, and fresh and dry weight of shoots and roots of seedlings obtained from primed seeds were increased significantly compared to unprimed seeds. This improvement as affected by priming is supported by the findings of Basra *et al*. (2005), Rafiq *et al*. (2006), Afzal *et al*. (2006a, 2007b, 2008), Iqbal and Ashraf (2007) with wheat. Afzal *et al*. (2008) reported that the growth of wheat increased significantly by using 50 mM $CaCl_2$ as seed priming treatment in saline medium. Moreover, Rafiq *et al*. (2006) reported that priming with $CaCl_2$ significantly enhanced shoot and root length under both saline and non-saline conditions.

The enhancement in growth parameters as affected by priming with $CaCl_2$ is probably due to increased availability of water which led to increased cell division rate in the root tip, and thus improved seedling growth (Afzal *et al*. 2006a). Easterwood (2002) reported that Ca^{2+} is an important part of cell wall structure and cell division. Furthermore, Afzal *et al*. (2007b) suggested that the increase in shoot and root length due to seed priming with 50 mM of $CaCl_2$ could be due to an increase in embryo cell wall extensibility as affected by Ca^{2+}. In addition, this improvement could be due to the effect of Ca^{2+} on the Na^+ ions in saline environments. It has been reported that Ca^{2+} mitigates the negative effect of Na^+ on the growth of plants (Rehman *et al.* 2000; Faiza *et al*. 2007; Gobinathan, Murali, and Panneerselvam 2009). Furthermore, Afzal *et al*. (2007b) studied the effects of priming with 50 mM $CaCl_2$ on the growth of wheat, and suggested that the enhancement of shoot and root length, and fresh and dry weight of shoots and roots is probably due to the improvement in embryo cell wall division rate as affected by Ca^{2+}.

3.3.4. Chapter Conclusion

It can be concluded that salinity stress significantly inhibited the growth of cv. Slambo and cv. S-24 by decreasing their germination and growth parameters. However, among all tested priming treatments, halopriming with 50 mM $CaCl_2$ was the most successful treatment that increased the ability of the two wheat cultivars to grow under saline conditions by alleviating the inhibitory effect of salt stress. This was demonstrated by improved G%, GR, and MGT under laboratory conditions. Also halopriming with $CaCl_2$ enhanced E%, ER, shoot and root length, and fresh and dry weight of shoots and roots under greenhouse conditions. It can be also concluded that both cultivars showed similar performance under saline conditions for almost all parameters measured. The improvements in these germination and growth parameters can possibly be explained by the effect of $CaCl_2$ on membrane integrity, the absorption of water, and Na^+ toxicity. These aspects are investigated in more detail in Chapter 6. The next chapter (4) focuses on the effect of compost on emergence and growth of wheat seeds.

Chapter 4

The Response of Wheat (*Triticum aestivum* L.) to Compost

4.1. Interaction

Compost is an organic product resulting from decomposition processes (Darlington 2001). Composts differ in nutrient content. The quality of compost and the variation among composts in terms of their nutrient content is correlated withthe type of material which is used (Tilston *et al.* 2005). This material can be yard waste, sewage sludge, animal manure, plant residues, leaves, biodegradable packing and food scraps. The beneficial effect of compost on plant growth is due to it supplying nutrients (Jacques and Mohamed 2004), enhancing the structure of soil, and increasing water retention capacity (Aggeliides and Londra 2000).

Compost is widely known to enhance plant growth (Ibrahim *et al.* 2008), but many questions remain unanswered for wheat. For example, is there a difference in the response among wheat cultivars to compost? What is the best concentration of compost to be applied for growing wheat? Is there a difference among composts in term of enhancing the growth of wheat under saline conditions? Therefore, this chapter aimed to answer these questions and to determine the best compost concentration that can enhance the growth parameters of wheat under non-saline and saline conditions.

Two composts were obtained from The Woodhorn Group Ltd, namely earth cycle organic cow compost, which is a nutrient-dense organic soil conditioner based on composted cow manure from an organic dairy herd, and earth cycle greenwaste compost, which is a nutrient-dense organic soil conditioner based on composted plant material. According to the analysis report of composted material provided by the Woodhorn Group Ltd (See Appendix 32 +33), the concentration of nitrate in cow compost and greenwaste compost in dry matter was 47.3

and 0.6 mg kg^{-1} respectively. However, ammonium was 430 mg kg^{-1} in cow compost and 202 mg kg^{-1} in greenwaste compost. More information about extractable nutrients of both composts is in Appendix (32 + 33). These two composts were selected for use in this study due to their similarity to Libyan composts which are low cost and available for poor Libyan farmers.

4.2. Extractable nutrients in compost

Nutrients are very important for plant growth. Compost is one of the most important sources of the necessary nutrients and organic matter which increase the nutrients absorbed by the plant (Tilston *et al*. 2005). Compost contains a range of the basic nutrients which plants need for good growth. These nutrients include micronutrients and macronutrients. Plants need micronutrients in small amounts such as copper, manganese, iron and zinc. Macronutrients such as nitrogen, phosphorus, potassium, calcium and magnesium are needed in larger amounts. Therefore, this experiment aimed to determine the concentration of the important ions of two types of compost.

4.2.1. Material and Methods

Ion content (Na^{+}, Ca^{2+}, K^{+}, P^{+}, Mg^{2+} and Fe^{2+}) of cow and greenwaste compost were determined using ammonium nitrate for digestion followed by Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES). Samples of the two composts chosen for the experiment were first milled to pass through a 2 mm mesh. Five g of ground air-dried compost was then put in beaker and 50 ml of 1 M ammonium nitrate were added. The beakers were closed and put on a shaker for 30 min. The samples were filtered through a 125 mm Whatman No. 2 filter paper. Three replicates of each sample were used. Spikes, blanks and standards were prepared before using the ICP.

Data were statistically analysed using one way ANOVA. Tukey's test at $p \leq 0.05$ was used for separation of treatment means.

4.2.2. Results

One way ANOVA indicated that there was a significant effect of compost on the ion concentration (Table 4.1). Concentrations of Na^{+}, Ca^{2+}, K^{+}, P, Mg^{2+} and Fe^{+} in the compost are presented in Table 4.1. K^{+}, Fe^{2+}, P^{+}, and Na^{+} were significantly higher in cow compost than in greenwaste compost, while Ca^{2+} in greenwaste compost was significantly higher than in cow compost. However, there was no significant difference in Mg^{2+} concentration between the composts.

Table 4.1. Extractable nutrients in air-dried cow and greenwaste composts (n = 3).

Sample	Concentration ($mg.kg^{-1}$)					
	K^{+}	Ca^{2+}	Mg^{2+}	Fe^{2+}	P^{+}	Na^{+}
C C	17316.3^{a}	3368.1^{b}	828.8^{a}	7.3^{a}	178.6^{a}	1522.1^{a}
GC	7371.9^{b}	6189.4^{a}	920.0^{a}	2.7^{b}	50.7^{b}	1075.0^{b}

4.2.3. Discussion

Calcium is an essential part of cell wall structure and is important in cell division (Easterwood 2002). Calcium is also an important element for the development of new roots and root hair growth (Kelly 2004). The results showed that greenwaste compost had a significantly higher Ca^{2+} concentration than cow compost. This is probably due to the difference in the raw materials from which the composts were formed. Parida and Das (2004) reported that Ca^{2+} plays a key role in salt adaptation. Ca^{2+} application tends to alleviate the adverse effects of salinity on the growth of plants (Rehman *et al.* 2000; Gobinathan, Murali,

and Panneerselvam 2009). It has been reported that toxic effects of NaCl can be reduced by adding Ca^{2+} as this increases the K^+: Na^+ ratio (Parida and Das 2004; Gobinathan, Murali, and Panneerselvam 2009). Aslam *et al*. (2003) found that the growth and productivity of two rice cultivars in salt conditions were improved by the application of Ca^{2+}.

Potassium is an important nutrient for plant growth and maintenance (Zekri and Obreza 2009). Potassium regulates CO_2 supply and water loss from leaves due to its control in the opening and closing of stomata (Zekri and Obreza 2009). Thus, potassium is able to decrease the effects of some environmental stresses such as drought and salinity (Plant Nutrients 2009). Singh *et al.* (2009) reported that salt tolerance of various plant species can be enhanced by increased K^+ application. In this experiment, cow compost had a significantly greater K^+ content than greenwaste compost. This is probably because the material that involved in decomposition process was manure which is basically composed of digested grass and grain producing cow dung that is rich in K^+.

Phosphorus is essential for various life processes (Zekri and Obreza 2009). During photosynthetic processes, phosphorus is needed to transform light energy to chemical energy (ATP) (Kelly 2004). It is also essential for seed and flower formation. Iron is important for chlorophyll formation and young growing tissues (Fertilizers and Plant Nutrition 2010). Table 4.1 shows that cow compost contained higher concentrations of phosphorus and iron.

Magnesium is considered a key element of chlorophyll molecules (Kelly 2004), and also plays an important role as an enzyme activator (Kelly 2004). The results showed that both composts contained similar levels of Mg^{2+}.

Sodium concentration in cow compost was significantly greater than in greenwaste compost and has a negative effects on plant emergence and growth (Ahmadi, Emam, and Pessarakli 2009; Patel *et al*. 2010; Bhutta 2011) causing osmotic or toxic effect.

Nutrient content in cow and greenwaste composts is different due to the difference in their raw material that is used to form the compost. At this stage it could not be predicted which compost would improve the growth of wheat cultivars under salt stress, thus the effect of Ca^{2+}, K^{+}, Mg^{2+}, which are related to the salt tolerance, and their combination on the emergence and growth of the two cultivars weretested in chapter 6.

4.3. pH of Compost

The pH of growth media is a very important consideration for plants and since compost is a key growth medium, it is important to determine pH. Darlington (2001) reported that most mature composts have a pH of between 6 and 8 depending on the raw material composted. However, compost created from wood residues may have a pH as low as 4.5, while manure compost has an alkaline pH (8.0 - 8.5) (Darlington 2001). According to WRAP (2004) the recommended level of compost pH for plant growth is between 7.0 and 8.7. Hence, this experiment aimed to determine the pH of different concentrations of the two composts.

4.3.1. Material and Methods

The determination of compost pH was derived from ADAS (1986). The compost samples were air dried and sieved to pass through a 2 mm sieve. One scoop from each type of compost (10 g scoop filled and smoothed off level without topping) was put into a 50 ml glass beaker, and 25 ml of distilled water added. The beakers were closed and put on a shaker for 30 min at speed of approximately 275 strokes min^{-1}. The samples were then filtered. A pH meter (Corning pH Meter 220) was used to determine pH. The pH meter was calibrated using buffer solutions of pH 4 and pH 7. The pH electrode was put in the suspension and a reading was taken after 30s. pH can be classified as the following:strongly acid (pH < 5), moderately

to slightly acid (5.0 - 6.5), neutral (6.5 – 7.5), moderately alkaline (7.5 – 8.5), and strong alkaline (pH > 8.5) (Millere and Hills 2006).

4.3.2. Results

Table 4.2 shows the pH level of the composts analysed. According to the pH classification of Millere and Hills (2006), the results indicated that 100% cow compost, 100% greenwaste compost, and the mixture between cow and greenwaste compost at 50:50 were moderately alkaline. However, when the concentration of each was reduced to 10% and 30% by mixing with sand, the pH decreased to the neutral level in all compost treatments. On the other hand, the pH of sand was moderately to slightly acid.

Table 4.2. pH range of composts (n = 3).

Sample	Concentration of compost with repeat to sand		
	100%	30%	10%
CC	8.04 – 8.12	7.42-7.49	7.28-7.46
GC	7.59 – 7.79	6.96-7.09	6.79-7.01
MIX (50:50)	7.62 - 7.94	7.31-7.34	7.15-7.28
Sand	5.46 - 5.61		

4.3.3. Discussion

Plants differ in terms of their recommended level of pH due to the effect of pH on the availability of nutrients. Figure 4.1 shows the effect of different levels of pH on the availability of nutrients.

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Figure 4.1. The availability of important nutrients at different levels of pH

(Mathers 2001)

Nitrogen, an essential plant nutrient, is available to plants at pH > 5.5 (Spector 2001). However, acid soil can affect the microbial activity and slow the nitrification process. High levels of pH can cause volatilization of N and decrease the availability of N for plants (Mullen 2009). In this study, N is available at all investigated levels of composts. A pH between 6 and 7 is optimum for the availability of phosphorus for plants (Spector 2001). However, Mullen (2009) reported that phosphorus is present at high levels when the pH of soil is between 5.5 and 7.5 while pH < 5.5 causes dissolution of aluminium and iron minerals that bind with phosphorus in the soil solution making it unavailable for absorption by plants. According to the result in Table 4.2, mixtures of both composts at 30% and 10% by weight had a pH between 6.7 and 7.5 which makes phosphorus more available than with 100% compost.

Acid conditions can affect the availability of magnesium by leaching it out due to the competition of hydrogen, iron, and aluminium ions for cation exchange sites (Mullen 2009). Millere and Hills (2006) reported that phosphorus, nitrogen, potassium, sulphur, calcium, and manganese are not available to plants in acid soils less than 5.5. Therefore, all of these

elements are expected to be available in both cow and greenwaste composts. Thus, in this experiment when the compost is mixed with sand, pH increased to a sufficient level to make the nutrients available for plant uptake. Micronutrients such as Zn^{2+}, Al^{3+}, Fe^{2+}, Cu^{2+} and Mn^{2+} are soluble and available for uptake by plants in pH < 5.0. In more alkaline soil these ions are less available, and symptoms of nutrient deficiency may result, including thin plant stems, change in leaf colour to yellow (chlorosis), and slow or stunted growth. Thus, all micronutrient elements are expected to beless available in both cow and greenwaste composts as the pH >5.0. In this experiment compost helped buffer sand toward a neutral pH level. As the pH of sand is classified as moderately to slightly acid, pH increased to a largely neutral level. This was supported by the finding of Maynard (1997) who found that addition of organic matter could be used as an effective substrate in alleviating the pH of acid soil.

4.4. EC of Compost

Electrical conductivity (EC) is the most widely used indicator to rapidly estimate the soluble salts in soil, water and fertilizer solutions. Since the excessive application of organic products with high soluble salts has a negative effect on plant growth and soil quality, the electrical conductivity measurement is an essential indication of the quality of the growth medium. Therefore, this experiment aimed to determine the EC of the different types of compost. Wentz (2001) and Chhabra (1996) classified the electrical conductivity as follows: non-saline (EC < 2 dS m^{-1}), weakly saline (2 – 4 dS m^{-1}), moderately saline (4 - 8 dS m^{-1}), strongly saline (8 – 16 dS m^{-1}) and very strongly saline (EC > 16 dS m^{-1}).

4.4.1. Material and Methods

The same procedure as the pH experiment was used to determine EC of compost and an EC meter (PTI-8 Digital Conductivity Meter) was used calibrated with KCl.

4.4.2. Results

The results showed that the EC of cow compost is about twice that of greenwaste compost and considered moderately saline while greenwaste compost is weakly saline (Table 4.3). On the other hand, sand is considered as non-saline. However, when mixed at 30% with sand, the EC of both cow compost and the compost mixture were reduced to being weakly saline, but greenwaste compost at the same concentration was non-saline. Furthermore, at 10 % mixture with sand, all the compost treatments became non-saline.

Table 4.3. Range of EC ofcomposts (dS m^{-1}) (n = 3).

Sample	Concentration of compost with repeat to sand		
	100%	30%	10%
Cow Compost	6.19 – 6.45	3.05 – 3.53	1.32 – 2.00
Greenwaste Compost	2.58 – 2.84	1.57 – 1.66	0.81 – 0.94
Mixture (50:50)	4.17 - 4.62	2.13 – 2.82	0.97 – 1.44
Sand	0.19 – 0.30		

4.4.3. Discussion

Electrical conductivity (EC) is very important and is the most common measure of soil salinity, being the ability of a solution to carry an electric current. It is usually expressed in deci Siemens per metre (dS m^{-1}). Soluble salt levels in compost can differ significantly, depending on feed stock. Compost may therefore contribute to or dilute the accumulative soluble salt content in the amended soil. An understanding of soil salinity, compost salinity and plant tolerance to salinity is necessary for the successful establishment of plant material. Salinity (EC) should be less than 4 dS m^{-1} for arable land (Darlington 2001). Munns and Tester (2008) reported that the salinity threshold of most plants is approximately 4 dS m^{-1}. It has been reported that the growth of wheat will be affected by salinity when EC is more than 6 dS m^{-1} (Monasterio *et al.* 2002). Salinity levels higher than this level can be detrimental to

the germination of seeds and plants when the growing medium consists only of compost. However, because of the diluting effect of mixing the compost with soil, this damage will be decreased when the compost is applied as an amendment. Cow compost contains higher soluble salts than greenwaste compost. Therefore, the EC of cow compost is higher than that of the greenwaste compost. Darlington (2001) reported that soluble nutrients, mainly K^+, Ca^{2+} and Na^+, usually contribute most of the salinity in compost products. However, with the decrease of compost concentration, the EC decreased, which is due to the reduction in the soluble nutrients.

4.5. Organic Matter Content of Compost

Organic matter is a measure of the amount of carbon-based material in the compost. Aggeliides and Londra (2000) claimed that adding organic matter to the soil enhanced water holding capacity and increased concentration of nutrients which are very important for the growth of crops and healthy, active soil organisms (Tilston *et al.* 2005).

4.5.1. Material and Methods

In this stage, the organic matter (OM) content of each compostwas determined. Three air dried replicates of each compostwere placed in porcelain dishes and heated to 440 °C in a muffle furnace for 24 h. After cooling, the percentage of organic matter was determined using the following equation:

$$\text{OM\%} = \frac{(W2-W1)-(W3-W1)}{(W2-W1)} \times 100$$

Where:

W_1 = the weight of empty porcelain dish.

W_2 = the weight of porcelain dish with sample.

W_3 = the weight of porcelain dish with sample after heating and cooling.

The data collected were arcsine transformed and analysed using one way ANOVA. Tukey's test at $p \leq 0.05$ was usedfor separation of treatment means.

4.5.2. Results

The results showed that the organic matter content of the air dried greenwaste compost and cow compost was 65.26% and 64.83%, respectively. There was no significant difference ($p > 0.05$) in their organic matter content.

4.5.3. Discussion

The organic matter content of the growth medium is very important for the growth of plants. OM originates from plant and /or animal residues (Prasad and Power 1997; Robert 2008). Phipps (2010) reported that adding cow manure compost to the soil increased the amount of organic matter, provided beneficial bacteria, which can transfer nutrients into easily available forms, and decreased one third of greenhouse gas production, making it environmentally friendly.

According to WRAP (2004), the recommended level of organic matter in compost is more than 25% of dry weight. However, Darlington (2001) reported that high quality compost usually has a minimum of 50% organic matter content based on dry weight. Accordingly, the greenwaste compost and cow compost, used in this study, were both considered high quality composts because both of them contained more than 50% of organic matter. Since both types of compost contained a very similar amount of organic matter, both composts could be considered as high quality compost in terms of organic matter.

4.6. Total Nitrogen of Compost

Amongst all plant nutrients, nitrogen is considered the most essential element in the growth of plants and the productivity of crops. The total nitrogen in compost is typically defined as the sum of organic forms (proteins, urea, nucleic acids, and microbial biomass) and inorganic forms (ammonium, nitrite, and nitrate) of nitrogen. Microorganisms mineralize organic nitrogen to produce inorganic forms before it can be used by plants. The inorganic forms of nitrogen are available as nutrients for plants. Moreover, by the time organic nitrogen is available, the amount of nitrate in compost can be changed due to microorganism activity. Thus, the amount of nitrate in compost depends on the total nitrogen in compost and microorganism activity. Therefore, due to its importance to plants, total nitrogen in both composts was investigated.

4.6.1. Material and Methods

A modified Kjeldahl digestion was used to measure total nitrogen concentration in compost (Bremner and Mulvaney 1982). 0.5 g of air dried compost was weighed and put into a 250 ml digestion tube. 12 ml of salicylic acid and sulphuric acid mixture (25 g $HOC_6H_4CO_2H$ dissolved in 1 ml of concentrated H_2SO_4) were added, after that, contents were mixed thoroughly and left to stand overnight. 0.5 g of ground sodium thiosulphate ($Na_2S_2O_3$. $5H_2O$) was added to the tubes. The tubes were heated on a digestion block at 250 °C for 2 h. After the tubeshad cooled, two catalyst tablets (0.045 g $CuSO_4$. $5H_2O$, 0.045 g TiO_2 and 1.5 g K_2SO_4) were added and the tubes were heated again to 400 °C for another 2 h in a fume extractor. Two tablets of copper catalyst were added to the tubes. After that, the tubes were removed and left to cool. NH_4^+ was determined by steam distillation using Kjeltec Auto 1030 Analyzer and titrated against 0.1 HCl. The total N concentration was calculated using the following formula:

$$\text{Total } N_2\ (\%) = \frac{V1 - V2 \times M \times 14.01}{Weight of compost sample\ (mg)} \times 100$$

Where:

V_1 = the soil titre (ml HCl)

V_2 = the blank titre (ml HCl)

M = the molarity (ml HCl known to 4 decimal places)

Data were subjected to one way ANOVA. Tukey's test at $p \leq 0.05$ was used for separation of treatment means.

4.6.2. Results

One way ANOVA indicated that total nitrogen content was significantly higher ($p < 0.05$) in cow compost than in greenwaste compost. It was 17,800 mg kg^{-1} in CC and 14,742 mg kg^{-1} in GC with standard error 1.03 and 0.94, respectively.

4.6.3. Discussion

Nitrogen is a very important macronutrient for plant growth (Cechin and Fumis 2004) and is consumed by plants in large quantities (Degraff 2009) in forms that are readily available such as nitrate (NO_3^-) or ammonium (NH_4^+). Therefore, nitrogen is lost from the soil more quickly than any other nutrient which may cause a soil deficiency if a continual source of nitrogen is not applied (Degraff 2009).

Nitrogen has various functions in plants, and fundamentally all plant life processes rely on it (Zekri and Obreza 2009) such as photosynthesis and protein synthesis. Additionally, it is a key part of plant chlorophyll (California Foundation for Agriculture 2009; Plant Nutrients 2010) and many enzymes, which help organisms achieve biochemical processes and digest nutrients. It is also the essential element of plant proteins that build cell material and plant

tissues, including the genetic material DNA and RNA (California Foundation for Agriculture 2009). The results showed that nitrogen in cow compost was significantly higher than in greenwaste compost. This is probably due to the raw material. If the main material involved in the decomposition process was manure, then a high level of nitrogen will be present in compost (Compost Fundamentals 2007). As nitrogen content in cow and greenwaste compost was 17,800 and 10,055 mg kg^{-1} respectively, according to the typical nutrient content of compost (Table 2.4) both composts have an adequate amount of nitrogen. Thus, it is expected that both composts have the same effect on wheat growth in terms of nitrogen as they will be able to compensate for any deficiency of nitrogen.

4.7. The effect of the two composts on two wheat cultivars under non-saline and saline conditions

This experiment aimed to determine the best two compost treatments that enhance the growth of two wheat cultivars under saline conditions.

4.7.1. Material and Methods

10% and 30% greenwaste compost, 10% and 30% cow compost, and 50:50 mixture of both composts at 10% and 30% by weight made up with sand were used in this experiment. Four concentrations of NaCl (0, 100, 200 and 300 mM) were utilized to impose saline conditions. 13 cm plastic pots were used. Twenty seeds of each cultivar of wheat were sown in each treatment individually.

7 compost treatments (including control) × 2 wheat cultivars × 4 NaCl concentration = 56 treatments × 3 replicates = 168 pots.

Irrigation Regime

Three concentrations of NaCl were used as irrigation solutions in addition to distilled water as a control. Pots were subjected to 0, 100, 200, and 300 mM of NaCl to impose saline conditions once a week and when required. Emergence was recorded every day up to 35 days. After 35 days of sowing, emergence percentage, emergence rate, mean emergence time, fresh and dry weight of shoots and roots, and shoot and root length were determined as described in Chapter 3.

Data were statistically analysed using three way ANOVA. Tukey's test at $p \leq 0.05$ was used for separation of treatment means. The final emergence percentage was arcsine transformed before analysis.

4.7.2. Results

The increase in salinity concentration had a negative effect on all growth parameters measured. These growth parameters were significantly affected by the increase of salt stress levels in both wheat cultivars.

Emergence Percentage (E%)

Three way ANOVA showed that both compost treatment and NaCl concentrationhada significant effect ($p < 0.05$) on E%. Furthermore, the interaction between compost treatment and NaCl concentration was also significant (Table 4.4).

Table 4.4. The significance of interactions between treatments using ANOVA for E%.

Treatment Combination	Significant or not	P
Cultivar	NS	0.26
Compost treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar* Compost treatment	NS	0.70
Cultivar*NaCl Concentration	NS	0.65
Compost treatment * NaCl Concentration	S	<0.01
Cultivar* Compost treatment * NaCl Concentration	NS	0.06

Salinity significantly affected E% (Table 4.5). The E% decreased in both cultivars with the increase of NaCl level. levels ranged from 83 - 98% at 0 mM to 0 - 47% at 300 mM of NaCl. The first significant reduction in E% was recorded at 200 mM in all compost treatments except with cv. Slambo in 30% GC and with cv. S-24 in 30% mix where the first significant reduction in E% was at 300 mM. Furthermore, it was at 100 mM with cv. Slambo grown in 30% CC and 10% CC, and with cv. S-24 grown in 10% CC.

Table 4.5. Effect of different salinity levels on emergence percentage (E%) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in different compost treatments and in sand (mean values, range in brackets,*= no emergence, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	30%CC	96^{abc}(95-100)	65^{efg}(55-75)	20^{hij}(10-25)	*
	30%GC	93^{abcde}(85-100)	98^{a}(95-100)	70^{cdef}(60-85)	26^{ghij}(15-35)
	30%mix	93^{abcde}(90-95)	73^{bcdef}(65-80)	48^{fgh}(40-55)	*
	10%CC	96^{abc}(95-100)	66^{defg}(55-75)	05^{jk}(0-10)	*
	10%GC	93^{abcde}(85-100)	93^{abcde}(85-100)	08^{jk}(0-20)	*
	10% mix	91^{abcde}(85-95)	75^{bcdef}(65-85)	13^{hijk}(5-30)	*
	SAND	95^{abcd}(90-100)	76^{abcdef}(55-90)	03^{jk}(0-5)	*
S-24	30%CC	95^{abcd}(90-100)	70^{cdef}(50-80)	15^{hijk}(5-25)	*
	30%GC	98^{a}(95-100)	93^{abcde}(90-95)	73^{bcdef}(65-80)	46^{fghi}(35-65)
	30% mix	83^{abcdef}(80-90)	70^{cdef}(60-80)	51^{fg}(45-60)	*
	10%CC	96^{abc}(90-100)	68^{cdefg}(60-85)	10^{ijk}(5-15)	*
	10%GC	98^{a}(95-100)	83^{abcdef}(75-90)	11^{hijk}(10-15)	*
	10% mix	91^{abcde}(90-95)	90^{abcde}(80-100)	10^{ijk}(0-20)	*
	SAND	93^{abcde}(85-100)	78^{abcdef}(70-85)	21^{hij}(15-35)	*

The results showed that in both wheat cultivars, at 0 and 100 mM of NaCl, the E% in all compost treatments showed no significant difference compared to sand at the same NaCl

concentration. However, at 200 mM of NaCl, the highest E% was obtained from seeds grown in 30% GC followed by 30% mix, which were both significantly higher than sand at 200 mM for both cultivars. At 300 mM of NaCl, the only compost treatment resulting in any emergence in the two wheat cultivars was 30% GC while all seeds grown in the other treatments failed to emerge at this level of salinity. Moreover, 10% GC, 10% CC, and 10% mix failed to improve E% significantly compared to sand at all NaCl concentrations in both cultivars. Furthermore, there was no significant difference between E% of both cultivars grown in 30% GC at 300 mM and E% of almost all other treatments at 200 mM. Additionally there was no significant difference between cultivars in all compost treatments and at all NaCl concentrations.

Emergence Rate (ER)

Three way ANOVA showed that the effect of compost treatment and NaCl concentration on the ER was significant ($p < 0.05$). Moreover, the interaction between compost treatment and NaCl concentration, and the overall interaction were also significant (Table 4.6).

Table 4.6. The significance of interactions between treatments using ANOVA for ER.

Treatment Combination	Significant or not	P
Cultivar	NS	0.43
Compost treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar* Compost treatment	NS	0.57
Cultivar*NaCl Concentration	NS	0.10
Compost treatment * NaCl Concentration	S	<0.01
Cultivar* Compost treatment * NaCl Concentration	S	0.03

Salinity negatively affected the ER (Table 4.7). As NaCl concentration increased, ER of both cultivars decreased. The ER ranged from 0.177 - 0.219 in unstressed condition to 0 - 0.113 at 300 mM.

In both cultivars, the first significant drop in ER was recorded at 100 mM in all compost treatments except in 30% GC and 30% mix where the significant drop relative to unstressed treatment was recorded at 200 mM (Table 4.7). Moreover, the ER of cv. S-24 grown in 10% GC and 10% mix also dropped significantly at 200 mM.

Table. 4.7. Effect of different salinity levels on emergence rate ($1/T_{50}$) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in different compost treatments and in sand (mean values, range in brackets,*= no emergence, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	30%CC	0.17^{abc}(0.13-0.18)	0.11^{efghi}(0.10-0.11)	0.06^{hijkl}(0.05-0.08)	*
	30%GC	0.21^{a}(0.21-0.22)	0.18^{ab}(0.17-0.18)	0.14^{bcde}(0.14-0.15)	0.10^{efghij}(0.10-0.11)
	30%mix	0.19^{ab}(0.18-0.20)	0.14^{bcde}(0.12-0.16)	0.10^{efghij}(0.10-0.10)	*
	10%CC	0.21^{a}(0.21-0.22)	0.11^{efgh}(0.11-0.12)	0.03^{lm}(0.00-0.06)	*
	10%GC	0.20^{a}(0.19-0.21)	0.14^{bcde}(0.14-0.15)	0.04^{jklm}(0.00-0.07)	*
	10% mix	0.21^{a}(0.21-0.21)	0.12^{cdefg}(0.09-0.14)	$0.07^{fghijkl}$(0.06-0.09)	*
	SAND	0.21^{a}(0.19-0.23)	0.12^{cdefe}(0.12-0.13)	0.04^{klm}(0.00-0.06)	*
S-24	30%CC	0.19^{ab}(0.18-0.20)	0.11^{efgh}(0.10-0.12)	0.07^{ghijkl}(0.05-0.08)	*
	30%GC	0.21^{a}(0.21-0.22)	0.17^{abc}(0.17-0.17)	0.14^{bcde}(0.14-0.15)	0.12^{cdefg}(0.10-0.13)
	30% mix	0.19^{ab}(0.18-0.19)	0.14^{bcde}(0.13-0.17)	0.10^{efghi}(0.06-0.10)	*
	10%CC	0.19^{ab}(0.19-0.20)	0.12^{cdefe}(0.12-0.13)	$0.09^{efghijk}$(0.09-0.10)	*
	10%GC	0.18^{ab}(0.17-0.20)	0.14^{bcde}(0.13-0.15)	$0.07^{fghijkl}$(0.05-0.10)	*
	10% mix	0.19^{ab}(0.16-0.22)	0.14^{bcde}(0.13-0.15)	0.05^{ijklm}(0.00-0.10)	*
	SAND	0.21^{a}(0.21-0.22)	0.12^{defgh}(0.10-0.13)	0.05^{jklm}(0.04-0.05)	*

The results also showed that there was no significant effect of the different compost treatments on the ER at 0 mM of NaCl in both cultivars. 30% GC was the only treatment that had a significantly higher ER than sand at 100 mM in both wheat cultivars. Furthermore, at 200 mM, compared with sand, 30% GC followed by 30% mix were the only two compost treatments that gave a significantly higher ER than in sand at the same NaCl concentration in both cultivars. At 300 mM, the only treatment that recorded any emergence rate was 30% GC and was not significantly differ from almost all other treatments at 200 mM.

The effect of cultivar on the ER was not clear except with 10% CC at 200 mM where ER of cv. S-24 was significantly higher than in cv. Slambo.

Mean Emergence Time (MET)

ANOVA indicated that NaCl concentration and the interaction between NaCl concentration and compost treatment had a significant effect on the MET ($p < 0.05$) (Table 4.8).

Table 4.8. The significance of interactions between treatments using ANOVA for MET.

Treatment Combination	Significant or not	P
Cultivar	NS	0.46
Compost treatment	NS	0.44
NaCl concentration	S	<0.01
Cultivar* Compost treatment	NS	0.22
Cultivar*NaCl Concentration	NS	0.57
Compost treatment * NaCl Concentration	S	<0.01
Cultivar* Compost treatment * NaCl Concentration	NS	0.38

Table. 4.9. Effect of different salinity levels on mean emergence time (MET) (days) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in different compost treatments and in sand (mean values, standard error in brackets, * = no emergence, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	30%CC	6.4^{cdef}(0.2)	9.7^{abcde}(0.2)	14.9^{abc}(0.6)	*
	30%GC	5.2^{ef}(0.1)	6.4^{cdef}(0.1)	7.3^{abcdef}(0.1)	10.1^{abcde}(0.2)
	30%mix	6.0^{def}(0.1)	7.5^{bcdef}(0.4)	11.8^{abcde}(0.7)	*
	10%CC	5.1^{ef}(0.1)	9.1^{bcde}(0.4)	12.0^{abcde}(1.1)	*
	10%GC	5.3^{ef}(0.1)	7.6^{bcdef}(0.2)	9.6^{abcde}(0.3)	*
	10% mix	5.2^{ef}(0.1)	9.0^{bcde}(1.0)	14.3^{abcd}(0.6)	*
	SAND	5.2^{ef}(0.2)	8.5^{bcdef}(0.2)	10.3^{abcde}(0.3)	*
S-24	30%CC	5.9^{def}(0.2)	9.6^{abcde}(0.1)	15.1^{abc}(2.1)	*
	30%GC	5.2^{ef}(0.1)	6.5^{cdef}(0.2)	7.7^{bcdef}(0.3)	9.7^{abcde}(0.9)
	30% mix	6.0^{def}(0.1)	7.7^{bcdef}(0.5)	12.0^{abcde}(1.4)	*
	10%CC	5.7^{def}(0.1)	8.8^{bcdef}(0.5)	10.7^{abcde}(0.1)	*
	10%GC	6.0^{def}(0.2)	7.9^{bcdef}(0.2)	15.9^{ab}(1.8)	*
	10% mix	5.7^{def}(0.2)	7.5^{bcdef}(0.3)	9.3^{bcde}(1.3)	*
	SAND	5.1^{ef}(0.7)	8.8^{bcdef}(0.8)	18.5^{a}(0.8)	*

The results showed that for majority of treatmentsat 0, 100 and 200 mM of NaCl concentrations there was no significant difference from sand (Table 4.9). The exceptions were at 200 mM with cv. S-24 grown in 30% GC and 10% mix where the MET was significantly lower than that of sand at the same NaCl concentration. Moreover, there was no

significant difference between MET in 30% GC at 300 mM and the MET of all other treatments at 200 mM. In addition, there was no significant difference between the two cultivars.

Shoot and Root Length

Shoot Length

ANOVA indicated that cultivar, compost treatment and NaCl concentration had a significant effect on shoot length ($p < 0.05$).Furthermore, the interaction between compost treatments and NaCl concentration, and the overallinteraction werealso significant ($p < 0.05$) (Table 4.10).

Table 4.10. The significance of interactions between treatments using ANOVA for shoot length.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Compost treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar* Compost treatment	NS	0.87
Cultivar*NaCl Concentration	NS	0.24
Compost treatment * NaCl Concentration	S	<0.01
Cultivar* Compost treatment * NaCl Concentration	S	0.02

Shoot length was significantly affected by the increase of NaCl concentration in both wheat cultivars (Table 4.11). Shoot length ranged from 18.48 - 27.48 cm at 0 mM to 0 –11.41 cm at 300 mM. The first significant reduction was recorded at 100 mM in all treatments except in 30% GCwith both cultivars, and in 30% mix and sand with cv. Slambo, where the significant reduction was recorded at 200 mM. Shoot length in both cultivars was significantly affected by compost treatments. At 0 mM, all the compost treatments failed to increase the length of shoots significantly as compared to control except in 10% mix where shoot length of cv.

Slambo was significantly greater than with sand. However, at 100 and 200 mM, the only treatment that had a significantly greater shoot length was 30% GC for both cultivars.

Table. 4.11. Effect of different salinity levels on shoot length (cm plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in different compost treatments and in sand (mean values, standard error in brackets, * = no emergence, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	30%CC	23.0^{abcd}(0.5)	12.5^{ghij}(0.7)	5.1^{lmno}(0.4)	*
	30%GC	21.1^{bcdef}(0.6)	22.1^{abcdef}(0.9)	13.0^{ghij}(0.3)	9.2^{ijkl}(0.5)
	30%mix	21.0^{bcdef}(0.9)	16.3^{fgh}(0.7)	7.5^{jklmn}(0.6)	*
	10%CC	24.2^{abc}(0.7)	13.5^{ghij}(1.5)	17.0^{o}(0.5)	*
	10%GC	21.5^{abcdef}(0.8)	14.2^{ghi}(0.4)	2.1^{no}(1.1)	*
	10% mix	27.4^{a}(2.2)	13.1^{ghij}(0.8)	3.4^{lmno}(0.2)	*
	SAND	18.4^{cdefg}(1.1)	13.0^{ghij}(0.7)	2.8^{mno}(1.4)	*
S-24	30%CC	25.5^{ab}(1.0)	13.0^{ghij}(0.5)	3.3^{lmno}(0.4)	*
	30%GC	22.6^{abcde}(0.4)	22.6^{abcde}(0.7)	16.2^{fgh}(0.7)	11.4^{hijk}(0.9)
	30% mix	24.2^{abc}(1.3)	16.6^{efgh}(0.7)	8.5^{ijklm}(0.3)	*
	10%CC	24.7^{ab}(0.4)	14.1^{ghi}(0.2)	5.9^{klmno}(0.3)	*
	10%GC	23.2^{abcd}(0.3)	13.1^{ghij}(0.3)	4.4^{lmno}(0.6)	*
	10% mix	26.9^{ab}(1.6)	17.8^{defg}(0.5)	3.5^{lmno}(0.7)	*
	SAND	22.0^{abcdef}(1.0)	13.7^{ghi}(0.6)	2.6^{mno}(0.9)	*

At 300 mM of NaCl, seedling growth was recorded only in 30% GC. At this concentration, shoot length was significantly higher in 30% GC at 300 mM than in 10% CC, 10% GC and sand with cv. Slambo, and in 10% GC, 30% CC, 10% mix and sand with cv. S-24. Moreover, there was no significant difference between the two cultivars in terms of shoot length across all treatments.

Root Length

Three way ANOVA showed that all factors and their combinations had a significant effect on the root length ($p < 0.05$) except the interaction between cultivar and NaCl concentration where the effect was not significant ($p > 0.05$) (Table 4.12).

Table 4.12. The significance of interactions between treatments using ANOVA for root length.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Compost treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar* Compost treatment	S	<0.01
Cultivar*NaCl Concentration	NS	0.92
Compost treatment * NaCl Concentration	S	<0.01
Cultivar* Compost treatment * NaCl Concentration	S	<0.01

Table. 4.13. Effect of different salinity levels on root length (cm plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in different compost treatments and in sand (mean values, standard error in brackets, $*$= no emergence, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	30%CC	15.8^{defgh}(0.7)	$11.5^{hijklmn}$(0.7)	6.5^{mnopqr}(0.2)	*
	30%GC	21.1^{abcd}(1.1)	19.8^{abcde}(0.1)	18.5^{bcdefg}(0.7)	$8.2^{klmnopq}$(1.6)
	30%mix	$19.1^{abcdefg}$(1.7)	17.8^{bcdefg}(0.8)	$10.1^{ijklmno}$(0.9)	*
	10%CC	15.9^{cdefgh}(0.5)	$8.3^{klmnopq}$(0.3)	2.8^{qrs}(1.4)	*
	10%GC	$19.2^{abcdefg}$(0.4)	$11.0^{hijklmno}$(0.8)	3.8^{pqrs}(1.2)	*
	10% mix	19.5^{abcdef}(1.3)	$9.8^{ijklmno}$(0.3)	5.9^{nopqr}(0.5)	*
	SAND	21.4^{abc}(0.9)	$9.0^{ijklmnop}$(0.1)	2.5^{rs}(1.2)	*
S-24	30%CC	$19.0^{abcdefg}$(1.1)	$11.4^{hijklmn}$(0.4)	5.5^{opqrs}(0.6)	*
	30%GC	24.1^{a}(1.4)	21.0^{abcd}(1.0)	19.9^{abcde}(0.5)	14.6^{efghi}(1.0)
	30% mix	21.0^{abcd}(1.0)	14.6^{efghi}(0.6)	$11.4^{higklmn}$(0.5)	*
	10%CC	13.7^{ghijk}(0.6)	11.5^{hijklm}(0.8)	5.5^{opqrs}(0.2)	*
	10%GC	23.3^{ab}(1.7)	14.1^{fghij}(0.6)	$8.0^{lmnopqr}$(0.4)	*
	10% mix	20.2^{abcd}(1.6)	13.6^{ghijkl}(0.9)	5.7^{opqr}(0.6)	*
	SAND	19.6^{abcdef}(1.4)	$8.8^{jklmnop}$(0.8)	3.5^{pqrs}(0.6)	*

The increase of NaCl concentration significantly affected root length (Table 4.13). Root length ranged from 13.7 – 24.1 cm at 0 mM to 0 – 14.6 cm at 300 mM. The first significant drop in root length occurred at 100 mM in all treatments except with cv. Slambo in 30% CC, 30% mix and sand at 200 mM, and with cv. S-24 in 10% CC, and at 300 mM with both cultivars in 30% GC.

Compost treatments significantly affected the root length. 30% GC followed by 30% mix were the only two treatments that increased the root length significantly as compared to sand at 100 and 200 mM of NaCl for both cultivars. Furthermore, the effect of cultivar occurred

only at 300 mM where the root length in cv. S-24 was significantly higher than in cv. Slambo. Root length in 30% GC at 300 mM was significantly greater than in sand at 200 mM with cv. Slambo. However, at 300 mM with cv. S-24, root length was significantly higher than in 30% CC, 10% CC, 10% mix, and sand all at 200 mM.

Fresh Weight of Shoots and Roots

Fresh weight of Shoots

Three way ANOVA showed that cultivar, compost treatment and NaCl concentration had a significant effect on the fresh weight of shoots ($p < 0.05$). Moreover, the interaction between compost treatment and NaCl concentration was also significant ($p< 0.05$) (Table 4.14).

Table 4.14. The significance of interactions between treatments using ANOVA for shoot fresh weight.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Compost treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar* Compost treatment	NS	0.17
Cultivar*NaCl Concentration	NS	0.21
Compost treatment * NaCl Concentration	S	<0.01
Cultivar* Compost treatment * NaCl Concentration	NS	0.29

Fresh weight of shoots was affected significantly by the increase of salt concentration in both wheat cultivars (Table 4.15). Shoot fresh weight ranged from 3.1 – 9.2 g at 0 mM but decreased to just 0 – 0.72 g at 300 mM. The first significant reduction in shoot fresh weight occurred at 100 mM in all compost treatments except in 30% GC where the first significant drop occurred at 200 mM with cv. Slambo and at 300 mM with cv. S-24.

Table. 4.15. Effect of different salinity levels on shoot fresh weigh (g plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in different compost treatments and in sand (mean values, standard error in brackets, * = no emergence, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	30%CC	7.3^{ab}(0.7)	$1.2^{ijklmno}$(0.1)	0.1^{no}(0.0)	*
	30%GC	6.8^{bcde}(0.5)	5.1^{ef}(0.2)	2.1^{hijklm}(0.2)	0.4^{lmno}(0.1)
	30%mix	7.1^{bcd}(0.6)	2.6^{hij}(0.3)	0.6^{klmno}(0.1)	*
	10%CC	8.3^{ab}(0.5)	$1.9^{hijklmno}$(0.4)	0.1^{no}(0.0)	*
	10%GC	4.6^{fg}(0.4)	2.2^{hijkl}(0.0)	0.1^{no}(0.0)	*
	10% mix	6.7^{bcde}(0.3)	$1.8^{hijklmno}$(0.3)	0.1^{no}(0.0)	*
	SAND	3.6^{fgh}(0.1)	$1.4^{ijklmno}$(0.3)	0.1^{no}(0.0)	*
S-24	30%CC	9.2^{a}(0.4)	2.2^{hijkl}(0.1)	0.1^{no}(0.1)	*
	30%GC	6.7^{bcde}(0.6)	5.2^{cdef}(0.2)	2.3^{dhijkl}(0.1)	0.7^{jklmno}(0.2)
	30% mix	8.5^{ab}(0.9)	3.0^{ghi}(0.3)	0.4^{lmno}(0.1)	*
	10%CC	7.5^{ab}(0.3)	2.3^{hijkl}(0.2)	0.1^{no}(0.1)	*
	10%GC	5.1^{def}(0.1)	2.3^{hijkl}(0.1)	0.1^{no}(0.0)	*
	10% mix	7.2^{bc}(1.0)	2.5^{hijk}(0.1)	0.1^{no}(0.1)	*
	SAND	3.1^{ghi}(0.4)	$1.5^{ijklmno}$(0.3)	0.2^{mno}(0.1)	*

In both wheat cultivars, in unstressed conditions, all the compost treatments increased the fresh weight of shoots significantly compared to sand except 10% GC, which failed to increase the fresh weight significantly for cv. Slambo. At 100 and 200 mM of salinity, 30% GC was the only treatment that had significantly higher shoot fresh weight than the control in both cultivars. In both cultivars, shoot fresh weight in 30% GC at 300 mM did not significantly differ from shoot fresh weight in almost all other treatments at 200 mM.

Fresh weight of Roots

Three way ANOVA indicated that compost treatment, NaCl concentration, and the interaction between compost treatment and NaCl concentration had a significant effect on the root fresh weight ($p < 0.05$) (Table 4.16).

Table 4.16. The significance of interactions between treatments using ANOVA for Root Fresh Weight.

Treatment Combination	Significant or not	P
Cultivar	NS	0.11
Compost treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar* Compost treatment	NS	0.81
Cultivar*NaCl Concentration	NS	0.88
Compost treatment * NaCl Concentration	S	<0.01
Cultivar* Compost treatment * NaCl Concentration	NS	0.60

Table. 4.17. Effect of different salinity levels on root fresh weigh (g plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in different compost treatments and in sand (mean values, standard error in brackets, * = no emergence, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	30%CC	2.5^{defg}(0.3)	0.6^{ijk}(0.1)	0.2^{jk}(0.1)	*
	30%GC	4.7^{ab}(0.7)	2.2^{efgh}(0.3)	1.0^{hijk}(0.1)	0.2^{jk}(0.1)
	30%mix	2.2^{efgh}(0.1)	1.0^{ghijk}(0.1)	0.5^{ijk}(0.0)	*
	10%CC	4.3^{bc}(0.5)	0.8^{hijk}(0.1)	0.1^{k}(0.1)	*
	10%GC	5.3^{ab}(0.2)	1.8^{efghi}(0.1)	0.1^{k}(0.1)	*
	10% mix	4.8^{ab}(0.5)	1.1^{ghijk}(0.1)	0.1^{k}(0.1)	*
	SAND	4.7^{ab}(0.6)	1.2^{ghijk}(0.2)	0.1^{k}(0.0)	*
S-24	30%CC	2.2^{efgh}(0.1)	1.1^{ghijk}(0.5)	0.1^{k}(0.0)	*
	30%GC	4.9^{ab}(0.3)	2.8^{cdef}(0.4)	1.1^{ghijk}(0.1)	0.5^{ijk}(0.1)
	30% mix	2.9^{cde}(0.3)	1.2^{ghijk}(0.1)	0.4^{ijk}(0.1)	*
	10%CC	3.9^{bcd}(0.1)	0.8^{hijk}(0.0)	0.2^{jk}(0.1)	*
	10%GC	6.2^{a}(0.5)	1.3^{fghijk}(0.2)	0.1^{k}(0.0)	*
	10% mix	4.7^{ab}(0.2)	1.3^{fghijk}(0.2)	0.2^{jk}(0.1)	*
	SAND	4.5^{b}(0.1)	1.7^{efghij}(0.5)	0.3^{jk}(0.1)	*

Fresh weight of roots of both cultivars was affected significantly by increase in salt concentration (Table 4.17). Root fresh weight ranged from 2.2 – 6.2 g at 0 mM to 0 – 0.5 g at 300 mM. Furthermore, all the compost treatments failed to increase the fresh weight of roots for both cultivars under all salt concentrations except 10% GC which significantly increased the fresh weight of roots of cv. S-24 at 0 mM. At same concentration, in both cultivars, 30% CC and 30% mix significantly reduced the root fresh weight as compared to sand. In both

cultivars, root fresh weight in 30% GC at 300 mM did not significantly differ from root fresh weight in almost all other treatments at 200 mM.

Dry Weight of Shoots and Roots

Dry Weight of Shoots

Three way ANOVA indicated that cultivar, compost treatment, NaCl concentration, and the interaction between compost treatment and NaCl concentration had a significant effect on the shoot dry weight ($p < 0.05$) (Table 4.18).

Table 4.18. The significance of interactions between treatments using ANOVA for shoot dry weight.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Compost treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar* Compost treatment	NS	0.70
Cultivar*NaCl Concentration	NS	0.11
Compost treatment * NaCl Concentration	S	<0.01
Cultivar* Compost treatment * NaCl Concentration	NS	0.99

Shoot dry weight was negatively affected by the increase in salinity (Table 4.19). This decrease was significant in all treatments. Shoot dry weight ranged from 0.75–1.49 g in unstressed conditions to 0 – 0.16 g at 300 mM. The first significant drop in shoot dry weight occurred at 100 mM in all treatments except with cv. Slambo in 30% GC and 30% mix where the first significant drop occurred at 200 mM. At 0 mM, shoot dry weight of cv. Slambo seedlings grown in 30% CC and 10% CC was significantly greater than in the control, while shoot dry weight of cv. S-24 grown in 30% GC and 30% mix was significantly greater than in the control.

Table. 4.19. Effect of different salinity levels on shoot dry weigh (g plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in different compost treatments and in sand (mean values, standard error in brackets, * = no emergence, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	30%CC	1.23^{abc}(0.11)	0.26^{ijklm}(0.04)	0.03^{klm}(0.01)	*
	30%GC	1.11^{abcd}(0.07)	0.95^{cde}(0.05)	$0.43^{ghijklm}$(0.04)	0.10^{ijklm}(0.02)
	30%mix	1.14^{abcd}(0.04)	0.71^{defgh}(0.04)	0.13^{ijklm}(0.01)	*
	10%CC	1.45^{a}(0.05)	0.35^{hijklm}(0.06)	0.04^{klm}(0.02)	*
	10%GC	0.88^{cdef}(0.03)	$0.40^{ghijklm}$(0.02)	0.01^{m}(0.01)	*
	10% mix	1.00^{bcd}(0.08)	0.32^{ijklm}(0.04)	0.02^{lm}(0.01)	*
	SAND	0.75^{defgh}(0.01)	0.22^{ijklm}(0.05)	0.01^{lm}(0.01)	*
S-24	30%CC	1.26^{abc}(0.14)	$0.46^{ghijklm}$(0.04)	0.02^{klm}(0.01)	*
	30%GC	1.41^{a}(0.06)	0.98^{bcd}(0.09)	0.40^{fghij}(0.02)	0.10^{ijklm}(0.04)
	30% mix	1.31^{ab}(0.30)	0.71^{defgh}(0.06)	0.10^{jklm}(0.02)	*
	10%CC	1.11^{abc}(0.26)	$0.40^{ghijklm}$(0.04)	0.03^{klm}(0.01)	*
	10%GC	0.97^{bcde}(0.03)	$0.44^{ghijklm}$(0.02)	0.02^{klm}(0.04)	*
	10% mix	1.24^{abc}(0.04)	$0.49^{fghijklm}$(0.03)	0.01^{lm}(0.01)	*
	SAND	0.81^{cdefg}(0.10)	0.32^{ijklm}(0.06)	0.02^{klm}(0.01)	*

Moreover, at 100 mM, in both cultivars, shoot dry weight of seedlings grown in 30% GC followed by 30% mix was significantly greater than those grown in the control. However, at 200 mM, 30% GC was the only treatment that had a significantly greater shoot dry weight than the control in both cultivars. In addition, at 300 mM, 30% GC shoot dry weight did not significantly differ from other treatments at 200 mM.

Dry Weight of Roots

Three way ANOVA indicated that compost treatment, NaCl concentration, and the interaction between cultivar and compost treatment, compost treatment and NaCl concentration, and the overall interaction had a significant effect on the root dry weight ($p < 0.05$) (Table 4.20).

The increase in NaCl concentration significantly decreased the root dry weight of both cultivars (Table 4.21). Root dry weight ranged from 0.51 – 1.39 g in unstressed condition to 0 – 0.06 g at 300 mM of NaCl. The first significant decrease in root dry weight in both cultivars

occurred at 100 mM in all the treatments except in 30% GC and 30% mix in both cultivars, and 30% CC in cv. S-24 where the significant drop occurred at 200 mM.

Table 4.20. The significance of interactions between treatments using ANOVA for root dry weight.

Treatment Combination	Significant or not	P
Cultivar	NS	0.38
Compost treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar* Compost treatment	S	<0.01
Cultivar*NaCl Concentration	NS	0.90
Compost treatment * NaCl Concentration	S	<0.01
Cultivar* Compost treatment * NaCl Concentration	S	<0.01

Table 4.21. Effect of different salinity levels on root dry weigh (g plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in different compost treatments and in sand (mean values, standard error in brackets, * = no emergence, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	30%CC	0.51^{efgh}(0.04)	0.15^{ij}(0.01)	0.10^{j}(0.02)	*
	30%GC	0.87^{bcd}(0.13)	0.59^{cdef}(0.06)	0.27^{fghij}(0.01)	0.10^{j}(0.01)
	30%mix	0.50^{efghi}(0.03)	0.24^{fghij}(0.01)	0.11^{j}(0.01)	*
	10%CC	0.91^{b}(0.10)	0.19^{hij}(0.02)	0.06^{j}(0.04)	*
	10%GC	0.94^{b}(0.04)	0.32^{fghij}(0.03)	0.03^{j}(0.01)	*
	10% mix	0.96^{b}(0.02)	0.26^{fghij}(0.01)	0.06^{j}(0.01)	*
	SAND	0.96^{b}(0.02)	0.24^{ghij}(0.02)	0.02^{j}(0.01)	*
S-24	30%CC	0.51^{efgh}(0.01)	0.19^{hij}(0.04)	0.06^{j}(0.01)	*
	30%GC	0.72^{bcde}(0.01)	0.50^{efghi}(0.04)	0.31^{fghij}(0.01)	0.10^{j}(0.1)
	30% mix	0.58^{efgh}(0.07)	0.29^{fghij}(0.08)	0.08^{j}(0.01)	*
	10%CC	0.50^{efghi}(0.01)	0.14^{hij}(0.06)	0.04^{j}(0.01)	*
	10%GC	0.72^{bcde}(0.01)	0.24^{ghij}(0.06)	0.05^{j}(0.01)	*
	10% mix	1.39^{a}(0.23)	0.33^{fghij}(0.05)	0.08^{j}(0.03)	*
	SAND	1.03^{b}(0.13)	0.21^{fghij}(0.14)	0.04^{j}(0.03)	*

At 0 mM of NaCl, with cv. Slambo, all the treatments failed to increase the dry weight of roots, except with cv. S-24, where 10% mix was able to increase root dry weight significantly compared to sand. At 100 mM, the only treatment that increased the dry weight of roots was 30% GC at 100 mM with cv. Slambo. At 0 mM, some treatments significantly reduced the

root dry weight compared to sand including 30% CC and 30% mix in both cultivars, and 10% CC in cv. S-24. Root dry weight of both cultivars at 300 mM did not differ significantly from root dry weight in all other treatments at 200 mM.

Table 4.22. Summary of the effect of compost treatments on the emergence and seedling growth of wheat.

Cultivar	Treatment	NaCl	E%	ER	MET	Length		Fresh Weight		Dry Weight	
						S	R	S	R	S	R
Slambo	30% CC	0						✓	o	✓	o
		100									
		200									
		300									
	30%GC	0						✓			
		100		✓		✓	✓	✓		✓	✓
		200	✓	✓		✓	✓	✓		✓	
		300	✓	✓	✓	✓	✓	✓		✓	✓
	30%mix	0						✓	o		o
		100					✓			✓	
		200	✓	✓			✓				
		300									
	10% CC	0						✓		✓	
		100									
		200									
		300									
	10% GC	0									
		100									
		200									
		300									
	10% mix	0				✓		✓			
		100									
		200									
		300									
S-24	30% CC	0						✓	o		o
		100									
		200									
		300									
	30%GC	0						✓		✓	
		100		✓		✓	✓	✓		✓	
		200	✓	✓	✓	✓	✓	✓		✓	
		300	✓	✓	✓	✓	✓	✓		✓	✓
	30%mix	0						✓	o	✓	o
		100					✓			✓	
		200	✓	✓			✓				
		300									
	10% CC	0					o	✓			o
		100									
		200									
		300									
	10% GC	0						✓	✓		
		100									
		200									
		300									
	10% mix	0						✓			✓
		100									
		200			✓						
		300									

✓ = significant effect compared to control S = shoot.

O =significant negative effect compared to controlR = root.

4.7.3. Discussion

Many studies indicate that E%, ER and MET are affected by soil salinity (Rafiq *et al*. 2006; Mohammadi 2009; Patade, Bhargava, and Suprasanna 2009; Bajehbaj 2010; and Ashraf, Ashraf, and Ali 2010). The results of this study showed that E% and ER were reduced significantly as the salt concentration increased in both wheat cultivars as found by Rahman *et al*. (2008), Datta *et al*. (2009), Sayar *et al*. (2010a), and Akbarimoghaddam *et al*. (2011).

In the present study, 30% GC was the most successful treatment which improved the E% and ER significantly at all NaCl concentrations compared to controls, the next most successful was the 30% mix which showed significant improvement at 200 mM of salinity in both wheat cultivars. This enhancement in the E% and ER is most probably due to improved soil moisture status which results in increased water uptake rate. It may also be due to the increase in cell division caused by the elevated Ca^{2+} concentration as a result of compost addition (Soil Fertility Management- Plant Nutrients 2010). Chemical analysis of the composts showed that GC contained higher extractable Ca^{2+} and lower extractable Na^{+} than CC. Rafiq *et al*. (2006) pointed out that Ca^{2+} concentration could reduce Na^{+} toxicity under salt stress. Moreover, Lawson, Hayatsu, and Nioh (2004) reported that increasing external Ca^{2+} concentration inhibited Na^{+} absorption and improved the Ca^{2+}: Na^{+} and K^{+} : Na^{+} ratios in the plants, and thus might be an important factor in controlling salinity response of plants.

The effect of compost on shoot and root length was clearest in the 30% GC at 100, 200 and 300 mM followed by 30% mix in root length of both wheat cultivars. All the other compost treatments failed to increase the length of shoots and roots compared to sand as the control. The improvement of growth parameters due to the application of compost has also been reported by Lawson, Hayatsu, and Nioh (2004) in kidney bean, soybean and alfalfa, and Tilston *et al*. (2005), Ibrahim *et al*. (2008) and Deshmukh *et al*. (2011) in wheat.

The increase in shoot and root length is probably due to enhanced availability of nutrients due to compost application. Nevens and Reheul (2003) and Ibrahim *et al*. (2008) reported that organic materials such as compost improve the availability of nutrients and the efficiency of their use by slow release of nutrients and decreasing their loss. Lawson, Hayatsu, and Nioh (2004) reported that the addition of compost enhanced soil moisture status and exchangeable Ca^{2+} which could reduce the toxicity of Na^{+} in saline environments, thus improving plant growth. Furthermore, the application of compost increases soil microbial activities leading to enhanced nutrition (Ibrahim *et al*. 2008).

The results also showed that fresh and dry weight of shoots and roots was reduced markedly by the increase of salt concentration in both wheat cultivars. This is probably due to the disturbance of plant nutrition (Lakhdar *et al*. 2008). Kaya, Higgs, and Kirnak (2001) reported that the accumulation of Na^{+} is high in shoots and roots of plants exposed to salinity which results in a reduction of mineral nutrient uptake.

Under non-saline conditions, almost all the compost treatments significantly increased the fresh and dry weight of shoots. However, 30% GC was the only treatment that improved the fresh and dry weight of shoots significantly at 100, 200 and 300 mM in both wheat cultivars followed by 30% mix at 0 and 100 mM. This result is in agreement with Ibrahim *et al*. (2008) in wheat, Sarwar *et al*. (2008) in wheat and riceand Lakhdar *et al*. (2008) in *H. maritimum*. However, none of the compost treatments showed any effect on the fresh and dry weight of roots in both wheat cultivars at all NaCl concentrations except in dry weight at 100 and 300 mM with cv. Slambo and at 300 mM with cv. S-24 when the growth medium was 30% GC, and at 300 mM with cv. S-24 when the growth medium was 10% mix. This increase in shoot fresh and dry weight is probably due to the enhancement of water uptake and the availability of nutrients which are efficiently used by the plant leading to better growth (Ahmad *et al*. 2008; Ibrahim *et al*. 2008). As reported by Lakhdar *et al*. (2008), the growth of plants is often

positively related to nutrient uptake. Walker and Bernal (2008) pointed out that applying compost can enhance mineral nutrient status and growth of plants in saline soils. This enhancement in shoot dry weight is in accordance with Ibrahim *et al*. (2008) with wheat, Lakhdar *et al*. (2008) with *H. maritimum*.

4.8. Chapter Conclusion.

It can be concluded that the application of compost enhanced the nutrient content, pH, EC and organic matter of soil. Also it can be concluded overall that the application of 30% GC was the best compost treatment that improved almost all the growth parameters of both wheat cultivars under saline conditions followed by 30% mix. This improvement might be associated with enhanced water uptake by seedlings and the increase of nutrients especially Ca^{2+} as it is present in GC in higher amounst than in CC. Therefore, compost water holding capacity and the effect of adding Ca^{2+}, K^{+}, Mg^{2+}, and Ca^{2+}+ K^{+}+ Mg^{2+}were investigated in further experiments outlined in Chapter 6. The next chapter (5) focuses on the effect of the combination of selected priming treatment and the best two compost treatments.

Chapter 5

The Effect of the Combination of Priming and Compost on Seedling Emergence and Establishment of wheat cv. S-24 and cv. Slambo under Saline Conditions

5.1. Introduction

Soil salinity is one of the main abiotic stresses that influences the growth and productivity of crops (Ghogdi, Izadi, and Borzouei 2012). Many researchers have reported that presowing seed treatments enhance the growth and preformance of plants under saline conditions (Afzal *et al.* 2007a; Ghiyasi *et al.* 2008; Anwar *et al*. 2011). This enhancement can be attributed either to an increase in the speed of germination of seeds and / or to improved osmotic adjustment that increases the water uptake. Moreover, the growth and productivity of plants has also been reported to be improved by the application of compost (Tejada and Gonzalez 2003). Tilston *et al.* (2005) and Ibrahim *et al.* (2008) both found that wheat growth and yield were increased by the application of compost. This increase in growthis probably due to the provision of essential elements such as calcium and / or the improvement of the water holding capacity of the soil (Abdel-Mawgoud *et al*. 2010). Therefore, it is important to establish if a combination of both techniques improves the salt tolerance of both wheat cultivars to a greater extent than that obtained when each technique is applied separately.

This experiment was designed to investigate the effect of the selected priming treatment and the two selected compost treatments on the establishment of two cultivars of wheat subjected to salt stress.

5.2. Material and Methods

5.2.1. Laboratory Preparation

Before the experiment began, seeds of both cultivars were surface sterilized for 3 min with 1% sodium hypochlorite (NaOCl) and were rinsed using sterilized water. Seeds were soaked in 50 mM of the optimum priming solution ($CaCl_2$) determined in an earlier experiment (see Section 3.2) which was prepared prior to the experiment. Seeds were put in the growth incubator at 25°C. After 17 h of soaking, seeds of both cultivars were washed carefully with distilled water and then allowed to surface dry for few minutes (Afzal *et al.* 2008).

5.2.2. Greenhouse Preparation

The best two compost treatments, which were determined inan earlier experiment (see Section 4.7) were prepared before the start of the experiment as a growth medium. A mixture of 30% GC + 70% sand, and a mixture of 15% GC + 15% CC + 70% sand by weight were prepared. Pots were filled with these growth medias and sand as a control and twenty primed and unprimed seeds of two wheat cultivars were sown separately in each pot. The pots were irrigated with four different concentrations of NaCl (0, 100, 200 and 300 mM). Irrigation was to field capacity once a week until the end of the experiment, starting from the first day of the sowing. Each treatment consisted of five replicates. The experimental design was:-

2 priming treatments ×2 wheat cultivars × 3 growth media (including sand) × 4 NaCl concentrations = 48 treatments × 5 replicates = 240 pots.

Unprimed seeds sown in sand were considered as the control in this experiment.

In this experiment, emergence was recorded daily. After five weeks of sowing, seedlings were harvested and the following parameters were measured: Emergence percentage (%), emergence rate, the length of shoots and roots, fresh and dry weight of shoots and roots, as

well as seedling Na^+, Ca^{2+}, Mg^{2+} and K^+ content using the ICP method as described previously (Chapter 3).

5.3. Results

Emergence Percentage (E%)

Four way ANOVA showed that cultivar, compost, priming and NaCl concentration all have a significant effect ($p < 0.05$) on seed E% (Table 5.1). Additionally, the interaction between cultivar and compost, compost and priming, compost and NaCl concentrations, and compost, priming and NaCl concentrations were also significant ($p < 0.05$).

Table 5.1. The significance of interactions between treatments using ANOVA for E%.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	S	<0.01
Cultivar*Priming	NS	0.48
Cultivar*NaCl Concentration	NS	0.73
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	NS	0.34
Cultivar*Compost*Priming	NS	0.72
Cultivar*Compost* NaCl Concentration	NS	0.42
Cultivar*Priming* NaCl Concentration	NS	0.16
Compost*Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming*NaCl Concentration	NS	0.65

The effect of NaCl stress on E% is shown in Table 5.2. The results showed that with both cultivars, all three growing media and whether seeds were primed or not, E% declined with increasing NaCl concentration from 88 - 99% in unstressed seeds to 17 - 49% at 300 mM. The significant reduction was at 200 mM in 30% GC with both cultivars in primed and unprimed seeds, at 100 mM in 30% mix with cv. S-24 in primed and unprimed seeds, at 100

mM in 30% mix with cv. Slambo primed seeds and 200 mM with unprimed seeds. In sand, with both cultivars, it was at 100 mM in unprimed seeds and at 200 mM in primed seeds.

Table 5.2. Effect of different salinity levels on emergence percentage (E%) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, range in brackets, * = no emergence, n= 5)

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+P	98^{ab}(95-100)	90^{bcdefg}(85-100)	76^{fghij}(70-80)	43^{lmn}(35-50)
	30%GC+UP	88^{cdefgh}(85-90)	80^{fghi}(75-85)	55^{jklm}(50-60)	23^{nop}(20-25)
	30%mix+P	96^{abcd}(90-100)	84^{efgh}(75-90)	60^{ijkl}(50-75)	24^{nop}(20-30)
	30% mix+UP	90^{bcdefg}(80-100)	75^{ghij}(65-85)	42^{lmn}(30-50)	*
	SAND+P	95^{abcde}(90-100)	86^{cdefg}(75-95)	32^{mno}(25-35)	*
	SAND+UP	90^{bcdefg}(85-100)	63^{ijkl}(55-70)	11^{p}(5-15)	*
S-24	30%GC+P	99^{a}(95-100)	97^{ab}(90-100)	84^{efgh}(80-90)	49^{klm}(45-55)
	30%GC+UP	91^{abcdef}(85-100)	81^{fghi}(75-85)	63^{ijkl}(60-65)	34^{mno}(30-40)
	30% mix+P	97^{abc}(95-100)	85^{defgh}(80-90)	55^{jklm}(50-60)	17^{op}(10-25)
	30% mix+UP	89^{bcdefg} (80-95)	63^{ijkl}(55-70)	34^{mno}(20-45)	*
	SAND+P	97^{abc}(95-100)	91^{bcdefg}(85-95)	41^{lmn}(30-50)	*
	SAND+UP	89^{bcdefg}(80-100)	70^{hijk}(55-80)	23^{nop}(20-25)	*

With both cv. Slambo and cv. S-24, E% was unaffected by growth medium in unstressed conditions. With cv. Slambo it was significantly lower in sand than in 30% GC or in 30% mix at 200 mM NaCl with primed or unprimed seeds. With cv. S-24 E% of primed seeds was significantly higher in 30% GC than in 30% mix at 100 mM. However, at 200 mM the E% of primed and unprimed seeds grown in 30% GC was significantly greater than those grown in either 30% mix or in sand. Moreover, at 300 mM primed seeds sown in 30% GC had a higher E% than primed seeds sown in 30% mix.

Although ANOVA suggested an overall significant effect of cultivar on E% with cv.S-24 having a higher overall E%, almost all pairs analyses failed to identify significant differences between cultivars for growth medium, primingand NaCl concentration treatments.

The positive effects of the combination of priming and compost on E% was clear. In the combination of priming and 30% GC the E% was higher than the control at all NaCl

concentrations with both cultivars but not in unstressed conditions with cv. Slambo. In the combination of priming and 30% mix with cv. Slambo at 100 and 200 mM, and with cv. S-24 at 200 mM the E% was greater than in the control. At 300 mM no emergence was recorded in the control. In both wheat cultivars, the ability of seeds to emerge under all NaCl levels was clearly improved when the combination of priming and 30% GC was applied compared to other treatments.

Emergence Rate (ER)

Four way ANOVA showed that cultivar, compost, priming and NaCl concentrations had a significant effect ($p < 0.05$) on seed ER (Table 5.3). Furthermore, the interaction between cultivar and compost, cultivar and priming, compost and priming, compost and NaCl concentrations, cultivar, compost and NaCl concentration, cultivar, priming and NaCl concentration, compost, priming and NaCl concentration were also significant ($p < 0.05$).

Table 5.3. The significance of interactions between treatments using ANOVA for ER.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	NS	0.07
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	NS	0.07
Cultivar*Compost*Priming	NS	0.13
Cultivar*Compost* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	<0.01
Compost*Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming*NaCl Concentration	NS	0.19

The effect of NaCl stress on ER is shown in Table 5.4. The result showed that the increase of NaCl concentration reduced the emergence rate across all treatments. ER decreased from

0.183 – 0.31 in unstressed conditions to 0.06 – 0.1 at 300 mM. The most significant reduction was recorded at 200 mM in all treatments. However, in some treatments the reduction was recorded at 100 mM, for example, with cv. Slambo in primed and unprimed seeds sown in sand, with cv. S-24 in primed seeds sown in 30% mix, and in unprimed seeds sown in sand.

The effect of priming on ER was not significant except with cv. Slambo in 30% GC in unstressed conditions and at 100 mM NaCl, with cv. Slambo in sand at 200 mM, with cv. S-24 in 30% GC in unstressed conditions and at 100 mM, and with cv. S-24 in sand at 100 and 200 mM.

Table 5.4. Effect of different salinity levels on emergence rate ($1/T_{50}$) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, range in brackets, * = no emergence, n= 5)

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+P	0.26^{bc}(0.25-0.27)	0.22^{cd}(0.22-0.25)	0.12^{jklmn}(0.12-0.14)	0.08^{nopqr}(0.07-0.10)
	30%GC+UP	0.21^{def}(0.18-0.22)	0.17^{fghi}(0.16-0.17)	0.10^{lmnopq}(0.09-0.10)	0.08^{nopqr}(0.07-0.10)
	30%mix+P	0.19^{defg}(0.19-0.20)	0.17^{fghi}(0.15-0.20)	0.11^{klmnop}(0.09-0.20)	0.08^{nopqr}(0.06-0.10)
	30%mix+UP	0.19^{defg}(0.18-0.22)	0.16^{ghij}(0.14-0.21)	0.07^{pqrs}(0.07-0.09)	*
	SAND+P	0.20^{defg}(0.19-0.22)	0.11^{klmnop}(0.09-0.14)	0.09^{mnopqr}(0.08-0.12)	*
	SAND+UP	0.18^{defgh}(0.17-0.21)	0.09^{mnopqr}(0.08-0.11)	0.03^{st}(0.03-0.04)	*
S-24	30%GC+P	0.31^{a}(0.26-0.36)	0.28^{ab}(0.27-0.28)	0.13^{jklm}(0.11-0.14)	0.10^{lmnopq}(0.09-0.12)
	30%GC+UP	0.21^{defg}(0.16-0.26)	0.18^{efghi}(0.16-0.20)	0.12^{jklmno}(0.10-0.13)	0.09^{mnopqr}(0.08-0.10)
	30%mix+P	0.22^{cde}(0.19-0.25)	0.15^{hijk}(0.12-0.17)	0.10^{lmnopq}(0.10-0.11)	0.06^{qrs}(0.05-0.07)
	30%mix+UP	0.18^{defghi}(0.13-0.22)	0.13^{ijkl}(0.12-0.17)	0.08^{opqrs}(0.07-0.08)	*
	SAND+P	0.21^{def}(0.20-0.24)	0.18^{efghi}(0.16-0.20)	0.10^{lmnopq}(0.09-0.11)	*
	SAND+UP	0.19^{defgh}(0.16-0.22)	0.11^{klmnop}(0.10-0.13)	0.05^{rs}(0.05-0.06)	*

The effect of growing medium on the emergence rate was significant in some cases namely with cv. Slambo in 30% GC which was significantly higher than either in 30% mix or sand with primed seeds in unstressed conditions and at 100 mM, and cv. Slambo in 30% mix, which was significantly higher than in sand at 100 mM NaCl with primed seeds, with cv. Slambo in 30% GC was significantly higher than in sand at 200 mM with unprimed seeds, with cv. S-24 in 30% GC ER was significantly higher than in 30% mix or sand in unstressed

condition and at 100 mM with primed seeds. With cv. S-24 in sand ER was significantly lower than in 30% GC with unprimed seeds at 100 mM. With cv. S-24 in 30% GC, ER was significantly higher than in sand with unprimed seeds at 200 mM. In both cultivars at 300 mM there was no ER recorded with 30% mix in unprimed seeds and with sand in primed and unprimed seeds.

Cultivar affected emergence rate in some treatments, particularly in 30% GC where ER of cv. S-24 was significantly higher than with cv. Slambo with primed seedsin unstressed conditions and at 100 mM, and with sand where ER of cv. S-24 was significantly higher than cv. Slambo with primed seeds at 100 mM.

As compared to control, in both cultivars, ER of seedlings obtained from the combination of priming and 30% GC was significantly higher than ER of the control at 0, 100, and 200 mM of NaCl. Moreover, ER of the combination of priming and 30% mix was significantly higher than ER of the control at 200 mMin both cultivars, and with cv. Slambo at 100 mM. Furthermore, ER of the combination of priming and 30% GC was significantly higher than ER of the combination of priming and 30% mix at 0 and 100 mM of NaCl in both cultivars.

The ER of both cultivars of seedlings obtained from the combination of priming and 30% GC was higher than the ER of seedlings obtained from either the combination of priming and 30% mix or sand especially at low NaCl concentrations.

Mean Emergence Time (MET)

Four way ANOVA indicated that cultivar, compost and NaCl concentration had a significant effect ($p < 0.05$) on the MET (Table 5.5). Moreover, the interaction between cultivar and compost, cultivar and NaCl concentration, compost and priming, compost and NaCl concentration, priming and NaCl concentration, cultivar, compost and NaCl concentration,

compost, priming and NaCl concentration, and the overall interaction between cultivar, compost, priming and NaCl concentration was also significant ($p < 0.05$).

Table 5.5. The significance of interactions between treatments using ANOVA for MET.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	NS	0.93
NaCl concentration	S	<0.01
Cultivar*Compost	S	<0.01
Cultivar*Priming	NS	0.62
Cultivar*NaCl Concentration	S	<0.01
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	NS	0.35
Cultivar*Compost* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.17
Compost*Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming*NaCl Concentration	S	0.04

Table 5.6 shows the effect of NaCl concentration on the MET of Slambo and S-24 cultivars. For all treatments, MET increased significantly as NaCl concentration increased from 100 mM to 200 mM. The MET increased from 4.2 - 7.1 days in unstressed condition to 10.3 – 13.8 days at 300 mM. The significant increase in MET was recorded at 200 mM in almost all treatments. However, in some treatments the increase was recorded at 100 mM, for instance, with cv. Slambo in primed and unprimed seeds sown in sand, with cv. S-24 in primed seeds sown in 30% mix, and in unprimed seeds sown in sand.

The MET was unaffected by priming in almost all treatments. However, in both wheat cultivars, a significant difference between primed and unprimed seeds was found in sand at 200 mM, with cv. S-24 in 30% mix at 200 mM, and with cv. S-24 in 30% GC in both unstressed condition and at 100 mM NaCl.

With cv. Slambo, the MET was unaffected by growing medium with primed or unprimed seeds in unstressed condition. However, at 100 mM, the MET in sand was significantly higher than in 30% GC or in 30% mix with primed and unprimed seeds. At 200 mM in 30%

GC MET was significantly lower than either in 30% mix or in sand with primed and unprimed seeds, while at the same NaCl concentration MET of umprimed seeds in 30% mix was significantly lower than in sand at the same NaCl concentration.

Table 5.6. Effect of different salinity levels on mean emergence time (MET) (days) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets, * = no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC + P	4.6^{rs}(0.1)	5.6^{opqrs}(0.0)	8.8^{ijkl} (0.3)	11.5^{cdefg} (0.5)
	30%GC +UP	5.5^{pqrs}(0.1)	6.7^{mnopq}(0.1)	10.4^{fghij}(0.1)	12.5^{bcde} (0.3)
	30% mix + P	5.9^{nopqrs}(0.1)	6.8^{mnop}(0.1)	11.4^{cdefg}(0.3)	13.2^{bc} (0.5)
	30% mix + UP	6.6^{mnopqr}(0.1)	7.5^{klmno} (0.3)	12.9^{bcd}(0.5)	*
	SAND+ P	5.5^{pqrs}(0.1)	9.9^{ghij}(0.3)	12.2^{bcdef}(0.2)	*
	SAND+ UP	6.1^{nopqrs}(0.3)	11.2^{defgh}(0.2)	17.0^{a}(0.2)	*
S-24	30%GC+ P	4.2^{s}(0.2)	4.8^{qrs}(0.1)	8.8^{ijkl}(0.1)	10.3^{fghij} (0.3)
	30%GC+UP	6.2^{nopqr}(0.3)	6.8^{mnop}(0.2)	9.1^{ijk} (0.2)	11.4^{cdefg} (0.4)
	30% mix+ P	6.0^{nopqrs}(0.1)	8.5^{jklm}(0.3)	10.7^{efghi}(0.4)	13.8^{b} (1.0)
	30% mix+ UP	7.1^{lmnop}(0.5)	8.5^{jklm} (0.2)	13.0^{bcd} (0.1)	*
	SAND+ P	6.3^{nopqr}(0.3)	7.7^{klmn}(0.2)	11.2^{defg} (0.3)	*
	SAND+ UP	6.5^{mnopqr}(0.2)	9.2^{hijk} (0.5)	14.1^{b}(0.6)	*

The effect of growing medium on the MET was significant in some cases. With cv. S-24, in 30% GC, MET was significantly lower than in sand with primed seeds in unstressed conditions, with cv. S-24 in 30% GC was significantly lower than either in 30% mix or in sand with primed seeds at 100 mM, while it was significantly lower than in sand with unprimed seeds at the same NaCl concentration. With cv. S-24 in 30% GC, at 200 mM, MET was significantly lower than in sand with primed and unprimed seeds, and lower than in 30% mix with unprimed seeds. With cv. S-24 in 30% GC was significantly lower than in 30% mix with primed seeds at 300 mM NaCl.The effect of cultivar on the MET was not significant in almost all treatments except with cv. S-24 where it was significantly lower than in cv. Slambo in sand with primed seeds at 100 mM and with unprimed seeds at 200 mM.

From the results it can be shown that the lowest time for emergence was recorded in seeds subjected to the combination of priming and 30% GC at all NaCl concentrations followed by the combination of priming and 30% mix.

Shoot and Root Length

Shoot Length

ANOVA indicated that cultivar, compost, priming, NaCl concentration and the interaction between all of them had a significant effect ($p < 0.05$) on shoot length of both wheat cultivars **(**Table 5.7).

Table 5.7. The significance of interactions between treatments using ANOVA for shoot length.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	S	<0.01
Cultivar*Compost* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	<0.01
Compost*Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming*NaCl Concentration	S	<0.01

Table 5.8 shows the effect of NaCl concentrations on the shoot length of both wheat cultivars. Shoot length of both wheat cultivars decreased significantly with the increase of NaCl concentration from a range of 18 – 33.1 cm in unstressed conditions to 4 – 10.5 cm at 300 mM NaCl. The strength of this decrease varied among the treatments, for example, the reduction occurred in both wheat cultivars at 200 mM when primed and unprimed seeds were

sown in 30% GC, while in 30% mix, it was at 100 mM with cv. S-24 and 200 mM with cv. Slambo.

Priming increased shoot length of both cultivars in all treatments compared to unprimed seeds. For cv. Slambo, this increase was significant with 30% GC in unstressed conditions, and at 100 and 200 mM, with 30% mix in unstressed conditions and at 100 mM, and in sand in unstressed conditions. With cv. S-24 significant differences were found with 30% GC in unstressed conditions, and at 100 and 200 mM, with 30% mix in unstressed condition and at 100 mM, and with sand in unstressed conditions and at 100 mM NaCl.

Table 5.8. Effect of different salinity levels on shoot length (cm plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets,*= no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	30.5^{ab} (1.1)	28.3^{bc} (0.5)	19.2^{ghij}(0.5)	6.2^{pqrs} (0.5)
	30%GC+UP	21.0^{fghi} (0.5)	22.0^{efgh} (0.5)	12.4^{mn}(0.5)	4.0^{stu} (1.3)
	30% mix+ P	24.9^{de} (0.4)	23.2^{def} (0.9)	9.1^{nop} (1.1)	4.8^{rst} (0.2)
	30% mix+ UP	21.2^{fghi} (0.8)	18.3^{ijk}(0.5)	7.8^{opqr} (0.4)	*
	SAND+ P	26.1^{cd} (0.5)	18.9^{hijk} (0.3)	3.7^{stu} (0.2)	*
	SAND+ UP	18.1^{ijk} (0.3)	16.2^{jkl}(0.3)	0.8^{uv} (0.0)	*
S-24	30%GC+ P	33.1^{a} (1.4)	30.3^{ab} (0.7)	22.1^{efgh} (0.7)	10.5^{mno} (0.4)
	30%GC+UP	23.7^{def} (0.4)	24.0^{def} (0.7)	15.7^{kl} (0.7)	8.4^{opq} (0.4)
	30% mix+ P	29.7^{b} (1.1)	25.9^{cd} (0.5)	10.6^{mno} (0.8)	5.6^{qrst} (0.8)
	30% mix+ UP	22.3^{efg} (0.3)	15.8^{kl} (0.4)	8.8^{opq} (0.4)	*
	SAND+ P	26.4^{cd} (0.3)	20.9^{fghi} (1.0)	4.8^{rst} (0.9)	*
	SAND+ UP	22.0^{efgh} (0.2)	13.4^{lm} (0.5)	2.4^{tuv} (0.2)	*

Growth medium also had a significant effect on shoot length of both cultivars in some cases. With cv. Slambo, shoot length of primed seeds grown in 30% GC was significantly greater than that of seeds grown in both 30% mix and sand for 0, 100 and 200 mM of NaCl, and shoot length of primed seeds grown in 30% mix was significantly greater than those from sand at 100 and 200 mM of NaCl. Moreover, with unprimed seeds, shoot length in 30% GC was significantly higher than in 30% mix or in sand at 100 and 200 mM, and significantly higher in 30% mix than in sand at 200 mM. With cv. S-24, the shoot length of primed seeds

grown in 30% GC at 0, 100, 200 and 300 mM of NaCl was significantly greater than those grown in 30% mix and sand. Moreover, the shoot length of primed seeds grown in 30% mix was significantly higher than those grown in sand at 0, 100 and 200 mM of NaCl. However, shoot length of unprimed seeds sown in 30% GC was significantly greater than those sown in 30% mix and sand at 100 and 200 mM, while shoot length of unprimed seeds sown in 30% mix was significantly higher than in sand at 200 mM. A significant difference between cultivars for individual growing medium, priming, and NaCl concentration was found in some treatments, in particular with primed seeds in 30% mix and with unprimed seeds in sand in unstressed condition, with unprimed seeds in 30% GC at 200 mM, and with primed and unprimed seeds in 30% GC at 300 mM. Shoot length in all cases was significantly higher in cv. S-24 than in cv. Slambo.

Root Length

For root length, ANOVA indicated that all treatments and cultivars were significant ($p < 0.05$) except the interaction between cultivar, priming, and NaCl concentration, and the overall interaction (Table 5.9).

Table 5.9. The significance of interactions between treatments using ANOVA for root length.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	S	<0.01
Cultivar*Compost* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.73

In both cultivars, compost treatments including sand and either primed or unprimed seeds, root length decreased with increasing NaCl concentration from a range of 16.74 – 29.46 cm in unstressed conditions to 4.0 – 14.26 cm at 300 mM (Table 5.10). The significant reduction of cv. Slambo occurred at 200 mM with primed and unprimed seeds sown in 30% GC or in 30% mix, while it was 100 mM with primed and unprimed seeds sown in sand. For cv. S-24 the reduction was recorded at 200 mM with primed and unprimed seeds grown in 30% GC. However, it was 100 mM in 30% mix and sand.

Table 5.10. Effect of different salinity levels on root length (cm plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets,$*$= no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	25.3^{bc} (0.6)	23.6^{bcde} (0.7)	20.7^{efgh} (0.9)	10.1^{opqr} (0.9)
	30%GC+UP	18.9^{fghi} (0.9)	17.5^{hijk} (0.8)	15.3^{jklm} (0.7)	8.0^{qrs} (0.8)
	30% mix+ P	18.7^{fghij} (0.4)	18.6^{fghij} (0.9)	11.3^{nopq} (0.3)	4.0^{tuv} (0.2)
	30% mix+ UP	18.5^{fghij} (0.7)	16.7^{ijkl} (0.6)	9.9^{opqr} (0.6)	*
	SAND+ P	20.0^{fghij} (0.3)	12.3^{mno} (0.7)	4.3^{tuv} (0.2)	*
	SAND+ UP	16.7^{ijkl} (0.4)	7.5^{rst} (0.5)	1.0^{vw} (0.1)	*
S-24	30%GC+ P	29.4^{a} (0.6)	26.5^{ab} (1.0)	24.1^{bcde} (0.6)	14.2^{klmn} (1.2)
	30%GC+UP	24.8^{bcd} (0.6)	21.9^{cdef} (0.7)	18.2^{ghij} (0.6)	11.8^{mnop} (0.1)
	30% mix+ P	25.7^{b} (0.3)	21.1^{efg} (0.5)	12.1^{mno} (0.1)	4.6^{stu} (1.0)
	30% mix+ UP	21.3^{defg} (0.5)	17.0^{ijkl} (0.3)	9.0^{opqr} (0.3)	*
	SAND+ P	21.5^{defg} (0.6)	14.0^{lmn} (0.3)	7.2^{rst} (0.5)	*
	SAND+ UP	17.1^{ijkl} (0.6)	8.4^{pqr} (0.6)	2.4^{uvw} (0.1)	*

With cv. Slambo, priming significantly increased the root length compared to unprimed seeds with 30% GC at 0, 100 and 200 mM of NaCl, and in sand at 100 mM. With cv. S-24 priming significantly increased the root length in 30% GC at 0, 100 and 200 mM of NaCl, in 30% mix at 0 and 100 mM, and in sand at 0, 100 and 200 mM of NaCl. The root length of cv. Slambo primed seeds grown in 30% GC was significantly greater than either in 30% mix or in sand at 0, 100, and 200 mM of NaCl, and significantly greater than in 30% mix at 300 mM, and in sand at 100 and 200 mM of NaCl. Furthermore, root length in unprimed seeds sown in 30% GC was significantly greater than that of seeds sown in 30% mix or in sand at 200 mM, and

than those grown in sand at 100 mM NaCl. In addition, root length of unprimed seeds grown in 30% mix was significantly higher than in sand at 200 mM. For cv. S-24, root length of primed seeds grown in 30% GC was significantly greater than those grown in 30% mix at 0, 100, 200 and 300 mM, and higher than primed seeds grown in sand at 0, 100 and 200 mM. Additionally, root length of primed seeds sown in 30% mix was significantly higher than in sand at 0, 100 and 200 mM of NaCl. Furthermore, the root length of unprimed seeds of cv. S-24 grown in 30% GC was significantly higher than those grown in sand at 0, 100 and 200 mM, and greater than in 30% mix at 100 and 200 mM, while in 30% mix it was significantly greater than in sand at 0, 100 and 200 mM. Root length of cv. S-24 was significantly greater than root length of cv. Slambo in unstressed conditions with primed and unprimed seeds grown in 30% GC and with primed seeds grown in 30% mix, at 100 mM with unprimed seeds grown in 30% GC and at 300 mM with primed and unprimed seeds sown in 30% GC.

It can be concluded that the combination of priming and 30% GC was the best treatment that significantly enhanced the root length of both cultivars as compared to all other treatments up to 200 mM and in some cases up to 300 mM.

Shoot and Root Fresh Weight

Shoot Fresh Weight

Four way ANOVA demonstrated that cultivar, compost, priming, and NaCl concentrations had a significant effect ($p < 0.05$) on shoot fresh weight (Table 5.11). Furthermore, all interactions between these factors were significant ($p < 0.05$) except for cultivar, compost and NaCl concentration, and the overall interaction.

Table 5.11. The significance of interactions between treatments using ANOVA for shoot fresh weight.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	S	<0.01
Cultivar*Compost* NaCl Concentration	NS	0.24
Cultivar*Priming* NaCl Concentration	S	<0.01
Compost*Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming*NaCl Concentration	NS	0.09

The effect of salinity on the shoot fresh weight is shown in Table 5.12. Shoot fresh weight declined with increasing NaCl level in all treatments with both wheat cultivars from a range of 3.20 – 13.17 cm in unstressed condition to 0.25 – 1.38 cm at 300 mM NaCl. The significant decrease in shoot fresh weight in 30% GC with primed and unprimed seeds of both cultivars was at 200 mM NaCl, while it was at 100 mM with cv. S-24 in primed and unprimed seeds sown in either 30% mix or in sand. However, with cv. Slambo, the significant reduction in shoot fresh weight of primed seeds grown in 30% mix was at 200 mM and it was at 100 mM in unprimed seeds in the same growth medium. The significant reduction of primed and unprimed seeds of cv. Slambo was at 100 mM when the growth medium was sand.

Priming significantly increased the fresh weight of shoots with cv. Slambo in 30% GC in unstressed conditions and 100 mM, in 30% mix at 100 mM, and in sand in unstressed conditions and 100 mM NaCl. With cv. S-24, priming significantly increased shoot fresh

weight in 30% GC in unstressed conditions, 100 and 200 mM NaCl, in 30% mix in unstressed conditions and 100 mM, in sand in unstressed conditions and 100 mM.

Table 5.12. Effect of different salinity levels on shoot fresh weight (g plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets,$*$= no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	10.7^{bc} (0.5)	9.1^{cd} (0.6)	3.1^{jklm} (0.1)	0.4^{op} (0.0)
	30%GC+UP	5.5^{efg} (0.3)	4.2^{ghij} (0.3)	1.9^{klmno} (0.2)	0.3^{op} (0.1)
	30% mix+ P	6.2^{ef} (0.6)	4.8^{fghi} (0.3)	1.3^{nop} (0.1)	0.3^{op} (0.0)
	30% mix+ UP	6.6^{e} (0.5)	2.8^{jklmn} (0.3)	0.5^{op} (0.0)	*
	SAND+ P	5.6^{efg} (0.2)	2.6^{jklmn} (0.2)	0.9^{op} (0.0)	*
	SAND+ UP	3.2^{ijklm} (0.2)	0.9^{op} (0.0)	0.1^{p} (0.0)	*
S-24	30%GC+ P	13.1^{a} (0.6)	11.8^{ab} (0.4)	5.3^{efg} (0.2)	1.3^{nop} (0.1)
	30%GC+UP	6.1^{ef} (0.4)	5.1^{efgh} (0.3)	1.5^{mnop} (0.2)	0.6^{op} (0.0)
	30% mix+ P	8.7^{d} (0.5)	5.1^{efgh} (0.3)	1.3^{nop} (0.2)	0.2^{op} (0.0)
	30% mix+ UP	6.8^{e} (0.4)	3.2^{ijkl} (0.1)	0.5^{op} (0.0)	*
	SAND+ P	6.4^{ef} (0.2)	4.0^{ghij} (0.1)	0.8^{op} (0.0)	*
	SAND+ UP	3.4^{hijk} (0.2)	1.6^{lmnop} (0.1)	0.2^{op} (0.0)	*

In both cultivars, the shoot fresh weight of primed seeds grown in 30% GC was significantly higher than of those grown in either 30% mix or in sand at 0, 100 and 200 mM, while shoot fresh weight of primed seeds grown in 30% mix was greater than in sand only with cv. Slambo at 100 mM, and with cv. S-24 in unstressed conditions. Moreover, shoot fresh weight of unprimed seeds of cv. Slambo grown in 30% GC was significantly greater than those grown in sand at 0, 100 and 200 mM, while in 30% mix it was higher than in sand at 0 and 100 mM. In cv. S-24, shoot fresh weight of unprimed seeds grown in 30% GC was significantly higher than in sand at 0 and 100 mM, and greater than in 30% mix at 100 mM.

The effect of cultivar on fresh weight of shoots was also apparent in many cases. The fresh weight of shoots was significantly higher in cv. S-24 than in cv. Slambo with primed seeds in 30% GC at 0, 100 and 200 mM, and in 30% mix in unstressed conditions.

Root Fresh Weight

Four way ANOVA showed that cultivar, compost, priming, and NaCl concentration had a significant effect ($p < 0.05$) on root fresh weight. Moreover, the interactions between cultivar and NaCl concentration, compost and priming, compost and NaCl concentration, priming and NaCl concentration, cultivar, compost and priming, cultivar, compost and NaCl concentration, and compost, priming and NaCl concentration were all significant ($p < 0.05$) (Table 5.13).

Table 5.13. The significance of interactions between treatments using ANOVA for root fresh weight.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	NS	0.71
Cultivar*Priming	NS	0.21
Cultivar*NaCl Concentration	S	0.04
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	S	<0.01
Cultivar*Compost* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.66

Root fresh weight declined with increasing NaCl level from a range of 2.2 – 6.8 g in unstressed seeds to 0.3 – 0.8 g at 300 mM NaCl with both cultivars, across all compost treatments including sand and with primed or unprimed seeds (Table 5.14). The root fresh weight reduced significantly across all treatments at 200 mM except with cv. S-24 in primed and unprimed seeds grown in sand, with cv. Slambo in primed seeds grown in 30% mix, and with cv. Slambo in unprimed seeds grown in sand, where is occurred at 100 mM NaCl.

Priming significantly increased root fresh weight compared to unprimed seeds with cv. Slambo in 30% GC at 0 and 100 mM and with cv. S-24 in 30% GC at 0, 100 and 200 mM, in 30% mix at 0 and 100 mM, and in sand at 100 mM.

Table 5.14. Effect of different salinity levels on root fresh weight (g plant^{-}1) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets,$*$= no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	6.3^{ab} (0.2)	5.5^{bcd} (0.3)	1.5^{klm} (0.4)	0.6^{lmn} (0.2)
	30%GC+UP	4.7^{cdef} (0.2)	3.8^{efgh} (0.1)	0.9^{lmn} (0.2)	0.3^{mn} (0.1)
	30% mix+ P	4.7^{cdef} (0.3)	2.8^{hij} (0.2)	0.9^{klmn} (0.1)	0.3^{mn} (0.0)
	30% mix+ UP	2.2^{ijk} (0.1)	1.0^{klmn} (0.1)	0.3^{mn} (0.0)	*
	SAND+ P	4.2^{defg} (0.2)	3.1^{ghi} (0.3)	0.6^{lmn} (0.1)	*
	SAND+ UP	2.8^{hij} (0.1)	0.8^{lmn} (0.0)	0.1^{n} (0.0)	*
S-24	30%GC+ P	6.8^{a} (0.7)	5.6^{abc} (0.2)	3.5^{fghi} (0.1)	0.8^{lmn} (0.0)
	30%GC+UP	4.0^{efgh} (0.4)	3.6^{fgh} (0.2)	1.2^{klmn} (0.2)	0.3^{lmn} (0.0)
	30% mix+ P	5.0^{bcde} (0.3)	4.0^{efgh} (0.2)	0.8^{lmn} (0.0)	0.4^{lmn} (0.0)
	30% mix+ UP	3.1^{ghi} (0.2)	2.2^{ijk} (0.0)	0.3^{mn} (0.0)	*
	SAND+ P	5.0^{bcde} (0.3)	3.3^{ghi} (0.1)	0.7^{lmn} (0.0)	*
	SAND+ UP	3.9^{efgh} (0.2)	1.6^{jkl} (0.1)	0.4^{lmn} (0.0)	*

The root fresh weight was also affected significantly by the growth medium. With cv. Slambo root fresh weight of primed seeds sown in 30% GC was significantly higher than those sown in either 30% mix or in sand at 0 and 100 mM, while this difference was significant at 0, 100 and 200 mM with cv. S-24. Moreover, with unprimed seeds of cv. Slambo grown in 30% GC root fresh weight was significantly greater than in 30% mix or sand at both 0 and 100 mM, while with cv. S-24 root fresh weight of unprimed seeds sown in 30% GC was significant higher than that in either 30% mix or in sand only at 100 mM of NaCl. The effect of cultivar on the root fresh weight was not significant for all growth media, priming, and NaCl concentrations except in GC 30% at 200 mM where root fresh weight of primed seeds of cv. S-24 was significantly higher than those of cv. Slambo.

It can be concluded that the combination of priming and 30% GC was the most successful treatment for increasing the shoot and root fresh weight of both cultivars, but there was little difference in the performance of both cultivars across all NaCl concentrations.

Shoot and Root Dry Weight

Shoot Dry Weight

Four way ANOVA showed that all individual treatments and the interactions between the treatments had a significant ($p < 0.05$) effect on the shoot dry weight, except the overall interaction (Table 5.15).

Table 5.15. The significance of interactions between treatments using ANOVA for shoot dry weight.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	S	<0.01
Cultivar*Compost* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	<0.01
Compost*Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming*NaCl Concentration	NS	0.11

The results of the different treatments are summarized in Table 5.16. Across all treatments, dry weight of shoots declined with increasing NaCl concentration from a range of 0.572 – 1.985 g in unstressed conditions to 0.02 - 0.13 g at 300 mM NaCl. These declines were significant at 200 mM with primed and unprimed seeds of both wheat cultivars grown in 30% GC, and it was at 100 mM when the growth media were 30% mix and sand.

Table 5.16. Effect of different salinity levels on shoot dry weight (g plant^{-}1) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets,$*$= no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	1.56^{b} (0.10)	1.38^{bc} (0.02)	0.58^{ghij} (0.01)	0.09^{pq}(0.00)
	30%GC+UP	1.14^{cde} (0.06)	0.95^{ef} (0.04)	0.45^{ijkl} (0.02)	0.06^{pq} (0.02)
	30% mix+ P	1.28^{cd} (0.13)	0.64^{ghi} (0.05)	0.22^{lmnopq}(0.01)	0.02^{q} (0.00)
	30% mix+ UP	1.11^{de} (0.06)	0.49^{ijk} (0.04)	0.15^{mnopq}(0.02)	*
	SAND+ P	0.83^{fg} (0.03)	0.35^{jklmno} (0.01)	0.05^{pq} (0.01)	*
	SAND+ UP	0.57^{hij} (0.03)	0.29^{klmnop}(0.01)	0.02^{q} (0.01)	*
S-24	30%GC+ P	1.98^{a} (0.07)	1.89^{a} (0.04)	0.78^{fgh} (0.02)	0.13^{nopq}(0.01)
	30%GC+UP	1.16^{cde} (0.07)	0.96^{ef} (0.05)	0.40^{ijklm} (0.01)	0.10^{opq} (0.01)
	30% mix+ P	1.36^{bcd} (0.12)	0.80^{fgh} (0.03)	0.35^{jklmno}(0.02)	0.02^{q} (0.01)
	30% mix+ UP	0.96^{ef} (0.03)	0.57^{hij} (0.02)	0.15^{mnopq} (0.09)	*
	SAND+ P	1.27^{cd} (0.01)	0.57^{hij} (0.02)	0.37^{jklmn} (0.01)	*
	SAND+ UP	0.95^{ef} (0.02)	$0.25^{klmnopq}$(0.01)	0.13^{nopq} (0.01)	*

Priming significantly increased shoot dry weight with cv. Slambo in 30% GC at 0 and 100 mM, and in sand at 0 mM NaCl. With cv. S-24 significant increases due to primiming were shown in 30% GC at 0, 100 and 200 mM NaCl, in 30% mix at 0 mM NaCl, and in sand at 0 and 100 mM NaCl.

The effect of growing medium on shoot dry weight was significant in many cases, particularly in primed seeds of both cultivars. In 30% GC, shoot dry weight of primed seeds was significantly greater than in 30% mix or in sand at 0, 100 and 200 mM NaCl, and that of primed seeds of cv. Slambo grown in 30% mix was significantly higher than in sand at 0 and 100 mM of NaCl. Furthermore, shoot dry weight of unprimed seeds of cv. Slambo grown in 30% GC was significantly higher than unprimed seeds grown in sand at 0, 100 and 200 mM, and higher than unprimed seeds grown in 30% mix at 100 and 200 mM. Shoot dry weight of unprimed seeds sown in 30% mix was significantly higher than those sown in sand in unstressed conditions. For cv. S-24, shoot dry weight of unprimed seeds sown in 30% GC was significantly higher than those sown in sand at 100 and 200 mM, and in 30% mix at 100

mM. Finally, shoot dry weight of unprimed seeds grown in 30% mix was significantly higher than in sand but only at 100 mM of NaCl.

The effect of cultivar on shoot dry weight was identified in some treatments, specifically in primed seeds sown in 30% GC at 0 and 100 mM, primed and unprimed seeds sown in sand at 0 mM, and in primed seeds sown in sand at 200 mM of NaCl. In all these treatments, shoot dry weight was significantly higher in cv. S-24 than in cv. Slambo.

Root Dry Weight

Four way ANOVA indicated that root dry weight was significantly affected ($p < 0.05$) by cultivar, compost, priming, and NaCl concentration (Table 5.17). Moreover, ANOVA also showed that the interaction between cultivar and priming, cultivar and NaCl concentration, compost and priming, compost and NaCl concentration, priming and NaCl concentration, and cultivar, compost and NaCl concentration was significant ($p < 0.05$).

Table 5.17. The significance of interactions between treatments using ANOVA for Root dry weight.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	NS	0.20
Cultivar*Priming	S	0.02
Cultivar*NaCl Concentration	S	<0.01
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	NS	0.28
Cultivar*Compost* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.50
Compost*Priming* NaCl Concentration	NS	0.54
Cultivar*Compost*Priming*NaCl Concentration	NS	0.90

In all treatments, the root dry weight decreased with the increase of NaCl concentration (Table 5.18). The root dry weight declined from 0.659 – 2.390 g in unstressed conditions to 0 – 0.09 g at 300 mM of NaCl. The significant decrease in root dry weight was at 200 mM NaCl when primed and unprimed seeds of cv. S-24 were grown in 30% GC or in 30% mix but it was at 100 mM in sand. However, with cv. Slambo, it was at 200 mM when primed and unprimed seeds were grown in 30% GC, but it was at 100 mM in 30% mix or in sand.

Table 5.18. Effect of different salinity levels on root dry weight (g plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets,$*$= no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	1.80^{cd} (0.04)	1.65^{cde} (0.02)	0.43^{op} (0.01)	0.04^{rs}(0.01)
	30%GC+UP	1.11^{hijk} (0.02)	0.94^{jklm} (0.05)	0.23^{pqrs}(0.01)	0.03^{rs}(0.01)
	30% mix+ P	1.50^{efg} (0.14)	0.93^{jklm} (0.05)	0.21^{pqrs}(0.01)	0.01^{s}(0.00)
	30% mix+ UP	0.85^{klm} (0.03)	0.35^{pq} (0.02)	0.10^{qrs} (0.01)	*
	SAND+ P	1.36^{efgh} (0.05)	0.86^{klm} (0.02)	0.06^{qrs} (0.00)	*
	SAND+ UP	0.65^{mno}(0.02)	0.21^{pqrs} (0.02)	0.02^{s}(0.00)	*
S-24	30%GC+ P	2.39^{a} (0.10)	2.11^{ab} (0.08)	0.74^{lmn}(0.02)	0.09^{qrs}(0.00)
	30%GC+UP	1.53^{def} (0.08)	1.30^{fghi} (0.08)	0.33^{pqr} (0.01)	0.05^{rs}(0.00)
	30% mix+ P	1.92^{bc} (0.09)	1.64^{cde} (0.06)	0.33^{pqr} (0.04)	0.04^{rs}(0.00)
	30% mix+ UP	1.28^{fghi} (0.04)	1.03^{ijkl} (0.04)	0.21^{pqrs}(0.01)	*
	SAND+ P	1.83^{bc} (0.16)	1.22^{ghij}(0.08)	0.35^{pq} (0.05)	*
	SAND+ UP	1.12^{hijk} (0.04)	0.50^{nop}(0.01)	0.10^{qrs} (0.01)	*

With both cultivars, priming significantly increased the root dry weight in all growing media at 0 and 100 mM, while at 200 mM the only significant effect of priming was recorded with cv. S-24 in 30% GC.

A significant effect of growing medium on root dry weight was also found. In both cultivars, root dry weight of primed seeds was significantly greater in 30% GC than in sand at 0, 100 and 200 mM. In primed seeds grown in 30% GC root dry weight was significantly greater than in primed seeds grown in 30% mix at 0 and 100 mMwith cv. Slambo, and at 0, 100 and 200 mM with cv. S-24. With cv. S-24 root dry weight of primed seeds sown in 30% mix was significantly higher than those sown in sand at 100 mM of NaCl.

The root dry weight from seeds of cv. S-24 was significantly higher than for cv. Slambo in all growing media whether seeds were primed or not at 0 and 100 mM, except in sand with unprimed seeds at 0 mM, and a significant difference was also apparent at 200 mM NaCl, with primed seeds grown in 30% GC.

Seedling Na^+ Content

Four way ANOVA showed that the effects of NaCl concentration, and the interaction between compost and priming, compost and NaCl concentration, priming and NaCl concentrations, and compost, priming, and NaCl concentration on the seedling Na^+ content were significant ($p < 0.05$) (Table 5.19).

Table 5.19. The significance of interactions between treatments using ANOVA for seedling Na^+content.

Treatment Combination	Significant or not	p
Cultivar	NS	0.50
Compost	NS	0.08
Priming	NS	0.11
NaCl concentration	S	<0.01
Cultivar*Compost	NS	0.76
Cultivar*Priming	NS	0.84
Cultivar*NaCl Concentration	NS	0.72
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	NS	0.94
Cultivar*Compost* NaCl Concentration	NS	0.99
Cultivar*Priming* NaCl Concentration	NS	0.99
Compost*Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming*NaCl Concentration	NS	1.00

The effect of NaCl stress on seedling Na^+ content is shown in Table 5.20. The results show that with both cultivars, all three growing media and whether seeds were primed or not, Na^+ concentration in seedlings increased significantly with an increase of NaCl concentration

from 0 mM to 100 mM in all cases, and from 100 mM to 200 mM, except for unprimed seeds grown in sand.

Table 5.20. Effect of different salinity levels on seedling Na^+ content (g kg^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in bracket, * = no emergences, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	0.4^{jk}(0.0)	8.9^{hi}(0.7)	32.8^{abcde}(0.9)	37.3^{abcd}(0.6)
	30%GC+UP	0.7^{jk}(0.0)	9.7^{hi}(0.4)	34.5^{abcd}(0.4)	41.1^{abcd}(0.5)
	30% mix+ P	0.6^{jk}(0.15)	12.4^{ghi}(0.8)	40.6^{abcd}(0.4)	40.1^{abcd}(0.4)
	30% mix+ UP	0.8^{jk}(0.0)	14.7^{efgh}(0.5)	44.2^{ab}(0.9)	*
	SAND+ P	0.8^{jk}(0.1)	19.1^{cdefgh}(0.2)	49.1^{ab}(0.2)	*
	SAND+ UP	1.0^{jk}(0.0)	$25.2^{abcdefg}$(0.8)	53.8^{a}(0.5)	*
S-24	30%GC+ P	0.4^{k}(0.1)	8.9^{i}(0.5)	31.7^{abcdef}(0.8)	36.6^{abcd}(0.8)
	30%GC+UP	0.7^{jk}(0.0)	11.3^{ghi}(0.7)	33.7^{abcd}(0.7)	39.8^{abcd}(0.6)
	30% mix+ P	0.6^{jk}(0.1)	13.2^{ghi}(0.7)	38.9^{abcd}(0.5)	43.6^{abcd}(0.6)
	30% mix+ UP	0.6^{jk}(0.1)	14.0^{fghi}(0.3)	42.3^{abc}(0.7)	*
	SAND+ P	0.7^{jk}(0.1)	17.7^{defgh}(0.5)	44.0^{abc}(0.9)	*
	SAND+ UP	0.9^{jk}(0.2)	23.3^{bcdefg}(0.5)	48.8^{ab}(0.6)	*

The effect of priming, growth medium and cultivar on the seedling Na^+ content was not significant in all treatments.

Seedling Ca^{2+} Content

Four way ANOVA showed that the effect of all the relationships on Ca^{2+} seedling content was significant ($p < 0.05$) except for the interaction between cultivar and priming, cultivar and NaCl concentration, and cultivar, compost and NaCl concentration (Table 5.21).

The effect of NaCl stress on seedling Ca^{2+} content is shown in Table 5.22. The result showed that with both cultivars, all three growing media and whether seeds were primed or not, Ca^{2+}concentration declined with increasing NaCl concentration from 2.314 - 10.289 (g kg^{-1}) in unstressed conditions to 1.228 - 4.344 (g kg^{-1}) at 300 mM.

Table 5.21. The significance of interactions between treatments using ANOVA for seedling Ca^{2+} content.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	S	<0.01
Cultivar*Priming	NS	0.97
Cultivar*NaCl Concentration	NS	0.10
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	S	<0.01
Cultivar*Compost* NaCl Concentration	NS	0.06
Cultivar*Priming* NaCl Concentration	S	<0.01
Compost*Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming*NaCl Concentration	S	<0.01

Table 5.22. Effect of different salinity levels on seedling Ca^{2+} content (g kg^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets, * = no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	9.3^{ab}(0.4)	7.6^{cde}(0.3)	5.8^{fghij}(0.6)	2.5^{mn}(0.2)
	30%GC+UP	7.6^{bcde}(0.4)	5.9^{fghi}(0.2)	2.6^{lmn}(0.0)	1.4^{nop}(0.2)
	30% mix+ P	6.0^{efgh}(0.1)	4.2^{jkl}(0.4)	2.2^{mn}(0.0)	1.2^{nop}(0.1)
	30% mix+ UP	6.4^{defg}(0.2)	3.7^{klm}(0.1)	1.6^{no}(0.2)	*
	SAND+ P	3.5^{klm}(0.1)	2.1^{mno}(0.1)	1.0^{nop}(0.0)	*
	SAND+ UP	2.3^{mn}(0.1)	1.2^{nop}(0.1)	0.5^{op}(0.0)	*
S-24	30%GC+ P	10.2^{a}(0.3)	8.5^{bc}(0.2)	6.5^{def}(0.1)	4.3^{ijk}(0.6)
	30%GC+UP	8.9^{abc}(0.3)	7.8^{bcd}(0.1)	4.6^{hijk}(0.3)	2.1^{mno}(0.6)
	30% mix+ P	6.8^{def}(0.2)	4.6^{hijk}(0.3)	2.6^{lmn}(0.3)	1.4^{nop}(0.3)
	30% mix+ UP	5.4^{fghij}(0.1)	4.3^{hijk}(0.0)	2.3^{mn}(0.4)	*
	SAND+ P	4.7^{ghijk}(0.3)	3.7^{klm}(0.4)	1.4^{nop}(0.2)	*
	SAND+ UP	3.5^{klm}(0.1)	1.8^{no}(0.3)	1.0^{nop}(0.1)	*

Priming did not significantly influence the seedling Ca^{2+} content except with cv. S-24 in 30% GC at 200 and 300 mM, and in sand at 100 mM and with cv. Slambo in 30% GC at 100 and 200 mM. For both wheat cultivars, Ca^{2+} content of seedlings obtained from primed seeds sown in 30% GC was significantly higher than Ca^{2+} content of seedlings obtained from

primed seeds sown in 30% mix or in sand at all NaCl concentrations except with cv. Slambo at 300 mM. Moreover, the seedling content of Ca^{2+} was not significantly higher in seedlings obtained from primed seeds sown in 30% mix than in sand, with cv. Slambo at 200 mM, and with cv. S-24 at 100 and 200 mM. Furthermore, Ca^{2+} content of seedlings obtained from unprimed seeds sown in 30% GC was also significantly higher than those sown in 30% mix or in sand at all NaCl levels except with cv. Slambo at 200 mM where the difference was not significant between seedlings sown in 30% GC and 30% mix. Additionally, compared with seedlings sown in sand, Ca^{2+} content was significantly higher in seedlings sown in 30% mix except with both cultivars at 200 and 300 mM. The positive effect of cultivar on the seedling Ca^{2+} content was identified in 30% GC seedlings derived from primed seeds at 300 mM and from unprimed seeds at 100 and 200 mM of NaCl.

Seedling K^+ Content

Four way ANOVA indicated that cultivar, compost, priming, and NaCl concentration had a significant effect ($P< 0.05$) on seedling K^+ content. Furthermore, the effect of the interaction between compost, priming, and NaCl concentration was also significant (Table 5.23).

Table 5.23. The significance of interactions between treatments using ANOVA for seedling K^+content.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	NS	0.83
Cultivar*Priming	NS	0.89
Cultivar*NaCl Concentration	NS	0.81
Compost*Priming	NS	0.12
Compost* NaCl Concentration	NS	0.20
Priming* NaCl Concentration	NS	0.56
Cultivar*Compost*Priming	NS	0.95
Cultivar*Compost* NaCl Concentration	NS	0.67
Cultivar*Priming* NaCl Concentration	NS	0.92
Compost*Priming* NaCl Concentration	S	0.02
Cultivar*Compost*Priming*NaCl Concentration	NS	0.95

Table 5.24.Effect of different salinity levels on seedling K^+content (g kg^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets,*= no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	42.7^{ab}(0.6)	38.3^{abcde}(0.9)	$26.8^{efghijklmn}$(0.8)	$15.7^{nopqrst}$(0.9)
	30%GC+UP	40.8^{abcd}(0.9)	$33.0^{abcdefgh}$(0.3)	$20.3^{ijklmnopqr}$(0.7)	9.9^{qrstu}(0.4)
	30% mix+ P	34.8^{abcdef}(0.9)	$28.3^{efghijkl}$(0.3)	$17.4^{klmnopqrst}$(0.2)	10.0^{qrstu}(0.7)
	30% mix+ UP	$31.0^{bcdefghij}$(0.4)	$22.5^{ghijklmnop}$(0.8)	14.6^{opqrst}(0.9)	*
	SAND+ P	$27.1^{efghijklmn}$(0.5)	$16.0^{mnopqrst}$(0.9)	7.2^{st}(0.67)	*
	SAND+ UP	$21.5^{hijklmnopq}$(0.4)	14.3^{opqrst}(0.3)	5.3^{t}(0.6)	*
S-24	30%GC+ P	44.5^{a}(0.2)	37.1^{abcde}(0.7)	$29.8^{cdefghij}$(0.5)	$17.4^{klmnopqrst}$(0.8)
	30%GC+UP	41.6^{abc}(0.5)	$32.5^{abcdefgh}$(0.6)	$23.9^{fghijklmnop}$(0.5)	12.6^{pqrst}(0.3)
	30% mix+ P	37.0^{abcde}(0.7)	$29.3^{defghijk}$(0.3)	$19.2^{jklmnopqrs}$(0.9)	13.4^{pqrst}(0.6)
	30% mix+ UP	$34.5^{abcdefg}$(0.5)	$27.9^{efghijklm}$(0.8)	$16.2^{mnopqrst}$(0.8)	*
	SAND+ P	$31.6^{bcdefghij}$(0.9)	$19.0^{jklmnopqrs}$(0.8)	9.1^{rst}(0.5)	*
	SAND+ UP	$26.3^{efghijklmno}$(0.7)	$16.6^{lmnopqrst}$(0.4)	6.2^{t}(0.9)	*

The effect of NaCl stress on seedling K^+ content is shown in Table 5.24. The result showed that the increase in NaCl concentration negatively affected K^+ content in both cultivars, all three growing media and whether seeds were primed or not. The decrease was from a value of 21.516 – 44.564 (g kg^{-1}) in unstressed condition to 9.930 – 17.453(g.kg^{-1}) at 300 mM. The significant reduction in seedling K^+ content was at 200 mM in all treatments.K^+ content of seedlings obtained from primed seeds was not significantly higher than that from unprimed seeds across all treatments.

In both wheat cultivars**,** whether seeds were primed or not, K^+ content of seedlings obtained from seeds sown in 30% GC was significantly higher than K^+ content of seedlings obtained from seeds sown in sand but not significantly higher than those sown in 30% mix at all NaCl concentrations. However, there was no significant difference between seedlings sown in 30% mix and in sand at all NaCl levels except with cv. Slambo at 100 mM.

The accumulation of K^+ in the seedlings of cv. S-24 was not significantly higher than cv. Slambo under any treatment.

Seedling Mg^{2+}Content

Four way ANOVA (Table 5.25) showed that cultivar, compost, priming and NaCl concentration had a significant effect ($p < 0.05$) on seedling Mg^{2+} content. Furthermore, the effect of the interaction between cultivar and compost, cultivar and NaCl concentration, compost and NaCl concentration, priming and NaCl concentration, cultivar, compost and NaCl concentration, and the overall interaction between cultivar, compost, priming and NaCl concentration was also significant ($p< 0.05$).

Table 5.25. The significance of interactions between treatments using ANOVA for seedling Mg^{2+}content.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	S	<0.01
Cultivar*Priming	NS	0.22
Cultivar*NaCl Concentration	S	<0.01
Compost*Priming	NS	0.07
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	NS	0.61
Cultivar*Compost* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.20
Compost*Priming* NaCl Concentration	NS	0.12
Cultivar*Compost*Priming*NaCl Concentration	S	<0.01

Seedling Mg^{2+}content was significantly influenced by salinity (Table 5.26). The seedling Mg^{2+} content decreased with the increase in salt level whether seeds were primed or not and sown in compost or not. This decrease was significant at 300 mM in all remaining treatments except in some treatments where it was significant at 200 mM, with priming and unprimed seeds of cv. Slambo grown in 30% mix, with priming and unpriming seeds of cv. S-24 grown in 30% GC, and with unpriming seeds of cv. S-24 grown in sand. The results showed that priming had no effect on seedling Mg^{2+} content in all growth mediums and under all NaCl concentrations for both cultivars.

An effect of growth medium was identified. With cv. Slambo, Mg^{2+} of seedlings obtained from unprimed seeds sown in 30% GC was significantly higher than Mg^{2+} of seedlings sown in either 30% mix or in sand in unstressed conditions. With cv. Slambo, Mg^{2+} concentration of seedlings derived from primed seeds sown in 30% GC was significantly higher than seedlings obtained from primed seeds sown in 30% mix at 100 and 200 mM of NaCl and sand at 200 mM. With cv. S-24, Mg^{2+} was significantly higher in seedlings derived from primed seeds sown in 30% GC than in 30% mix or sand at 0 mM NaCl and higher than sandat 100 mM.

Table 5.26. Effect of different salinity levels on seedling Mg^{2+} content (g kg^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets, * = no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	1.8^{abcde}(0.03)	2.0^{abc}(0.0)	1.8^{abcde}(0.4)	0.7^{jklmn}(0.0)
	30%GC+UP	1.8^{abcd}(0.03)	1.8^{abcde} (0.0)	$1.2^{defghijk}$(0.1)	0.5^{mn}(0.1)
	30% mix+ P	1.4^{cdefgh}(0.09)	$0.9^{ghijklmn}$(0.0)	0.6^{klmn}(0.4)	0.3^{n}(0.0)
	30% mix+ UP	$1.1^{fghijklm}$(0.1)	0.7^{ijklmn}(0.0)	0.3^{n}(0.1)	*
	SAND+ P	$1.2^{defghijk}$(0.0)	1.4^{cdefgh}(0.1)	0.6^{klmn}(0.1)	*
	SAND+ UP	$1.0^{ghijklmn}$(0.1)	0.7^{klmn}(0.14)	0.5^{lmn}(0.1)	*
S-24	30%GC+ P	2.5^{a}(0.2)	2.0^{abc}(0.1)	1.7^{bcdef}(0.0)	$0.8^{hijklmn}$(0.1)
	30%GC+UP	2.1^{ab}(0.1)	1.8^{abcde}(0.4)	1.4^{cdefgh}(0.1)	0.5^{mn}(0.1)
	30% mix+ P	1.7^{bcdef}(0.0)	1.7^{bcdef}(0.0)	$1.2^{defghijk}$(0.2)	0.5^{mn}(0.1)
	30% mix+ UP	1.6^{bcdefg}(0.1)	1.4^{cdefgh}(0.1)	$1.1^{efghijklm}$(0.3)	*
	SAND+ P	1.7^{bcdef}(0.1)	1.4^{defghi}(0.3)	$1.1^{fghijklm}$(0.1)	*
	SAND+ UP	1.6^{bcdefg}(0.0)	$1.3^{defghij}$(0.1)	$0.8^{hijklmn}$(0.1)	*

A significant difference between cultivars was found only in a few cases where Mg^{2+} concentration was higher in cv. S-24 than in cv. Slambo. Specifically in primed seeds grown in 30% GC at 0 mM NaCl, in primed and unprimed seeds grown in 30% mix at 100 mM, in unprimed seeds grown in sand at 100 mM, and in unprimed seeds grown in 30% mix at 200 mM.

Seedling Ca^{2+}: Na^{+} Ratio

ANOVA indicated that the effect of cultivar, compost, priming, and NaCl concentration on the Ca^{2+}: Na^{+} ratio were significant ($p < 0.05$) (Table 5.27). Moreover, the interaction between cultivar and compost, compost and priming, compost and NaCl concentration, priming and NaCl concentration, cultivar, compost, and NaCl concentration, and the interaction between compost, priming, and NaCl concentration was also significant ($p < 0.05$).

Table 5.27. The significance of interactions between treatments using ANOVA for the Ca^{2+}: Na^{+} ratio

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	S	<0.01
Cultivar*Priming	NS	0.10
Cultivar*NaCl Concentration	NS	0.08
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	NS	0.93
Cultivar*Compost* NaCl Concentration	S	0.02
Cultivar*Priming* NaCl Concentration	NS	0.18
Compost*Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming*NaCl Concentration	NS	0.81

The effect of NaCl stress on the seedling Ca^{2+}: Na^{+} ratio is shown in Table 5.28. The results showed that with both cultivars, all three growing media and whether seeds were primed or not, the Ca^{2+}: Na^{+} ratio reduced with increasing NaCl concentration from 2.2 – 25.9 in unstressed condition to 0 – 0.12 at 300 mM. This reduction was significant at 100 and 200 mM in both cultivars and across all treatments.

A significant effect of priming was recorded with cv. Slambo in 30% GC at 200 and 300 mM, with S-24 in 30% GC at 300 mM, and with cv. Slambo and cv. S-24 in sand at 100 mM.

The effects of growth medium on the Ca^{2+}: Na^{+} ratio were significant in many cases. With cv. Slambo the Ca^{2+}: Na^{+} ratio of primed seeds grown in 30% GC was significantly higher than that of primed seeds grown in 30% mix or in sand at all NaCl concentrations. In addition, the Ca^{2+}: Na^{+} ratio of primed seeds grown in 30% mix was significantly higher than primed seeds grown in sand at 0, 100, 200 and 300 mM. With cv. S-24 the Ca^{2+}: Na^{+} ratio of primed seeds sown in 30% GC was significantly greater than those sown in either 30% mix or in sand at all NaCl concentrations.

Table 5.28. Effect of different salinity levels on seedling Ca^{2+}: Na^{+} ratio of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets, * = no emergence, n = 5).

Cultivar	Treatment	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	21.46^{ab} (0.53)	0.86^{g} (0.04)	0.18^{kl} (0.02)	0.07^{mno} (0.01)
	30%GC+UP	9.67^{cd} (0.52)	0.63^{ghi} (0.03)	0.08^{mn} (0.00)	0.03^{pq} (0.01)
	30% mix+ P	9.65^{cd} (0.89)	0.35^{ijk} (0.05)	0.06^{mnop} (0.00)	0.03^{q} (0.00)
	30% mix+ UP	7.99^{cde} (0.66)	0.25^{jk} (0.01)	0.03^{opq} (0.01)	*
	SAND+ P	4.44^{ef} (0.64)	0.14^{lm} (0.01)	0.02^{qr}(0.00)	*
	SAND+ UP	2.28^{f} (0.11)	0.04^{nop} (0.01)	0.01^{r} (0.00)	*
S-24	30%GC+ P	25.90^{a} (0.53)	0.93^{g} (0.06)	0.21^{jkl} (0.00)	0.11^{lm} (0.01)
	30%GC+UP	12.22^{abc} (1.08)	0.70^{gh} (0.05)	0.17^{kl} (0.01)	0.05^{nop} (0.01)
	30% mix+ P	10.29^{bcd} (1.07)	0.35^{ijk}(0.01)	0.07^{mno} (0.01)	0.03^{q} (0.00)
	30% mix+ UP	8.56^{cde} (0.99)	0.31^{ijk} (0.01)	0.05^{nop} (0.01)	*
	SAND+ P	6.01^{de} (0.69)	0.20^{jkl} (0.01)	0.033^{pq} (0.01)	*
	SAND+ UP	4.94^{ef} (1.21)	0.07^{mno} (0.01)	0.022^{qr}(0.00)	*

Furthermore, the Ca^{2+}: Na^{+} ratio of unprimed seeds of both cultivars grown in 30% GC was significantly higher than unprimed seeds grown in sand at 0, 100 and 200 mM, and higher than unprimed seeds grown in 30% mix at 100 and 200 mM with cv. Slambo and at 100 and 200 mM with cv. S-24. The Ca^{2+}: Na^{+} ratio of unprimed seeds sown in 30% mix was also significantly greater than in sand at 0, 100 and 200 mM with cv. Slambo and at 100 and 200 mM with cv. S-24.

The effect cultivar on the seedling Ca^{2+}: Na^{+} ratio was not significant in all treatments except with unprimed seeds sown in 30% Gc at 200 mM where Ca^{2+}:Na^{+} ratio in cv. S-24 was significantly greater than in cv. Slambo.

Seedling K^{+}: Na^{+} Ratio

Four way ANOVA showed that the effect of cultivar, compost, priming, and NaCl concentration on the K^{+}: Na^{+} ratio was significant ($p < 0.05$) (Table 5.29). Furthermore, the interaction between compost and priming, compost and NaCl concentration, and priming and NaCl concentration, and compost, priming and NaCl concentration was also significant ($p < 0.05$).

Table 5.29. The significance of interactions between treatments using ANOVA for the K^{+}: Na^{+}ratio

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Compost	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Compost	NS	0.14
Cultivar*Priming	NS	0.35
Cultivar*NaCl Concentration	NS	0.22
Compost*Priming	S	<0.01
Compost* NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming	NS	0.66
Cultivar*Compost* NaCl Concentration	NS	0.05
Cultivar*Priming* NaCl Concentration	NS	0.39
Compost*Priming* NaCl Concentration	S	<0.01
Cultivar*Compost*Priming*NaCl Concentration	NS	0.19

Table 5.30 shows the effect of NaCl stress on the seedling K^{+}: Na^{+} ratio. The results showed that the K^{+}: Na^{+} ratio declines significantly as NaCl concentration increases. This decline was significant across all compost and priming treatments for both cultivars.

The positive effect of priming on the K^+: Na^+ ratio was not clear for both cultivars in all compost and priming treatments except at 0 mM with both cultivars in 30% GC, with cv. S-24 in sand at 200 mM, and with cv. Slambo in 30% GC at 300 mM.

Table 5.30. Effect of different salinity levels on seedling K^+: Na^+ ratio of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv.S-24) sown under priming ($CaCl_2$) and compost (30% GC and 30% mix) combination and in sand (mean values, standard errors in brackets, * = no emergence, n = 5).

Cultivar	Compost	NaCl (mM)			
		0	100	200	300
Slambo	30%GC+ P	97.1^{a} (0.7)	4.3^{f} (0.3)	0.8^{kl} (0.0)	0.4^{nop} (0.0)
	30%GC+UP	51.5^{bc} (0.7)	3.4^{fg} (0.1)	0.5^{lmn} (0.0)	0.2^{qr} (0.0)
	30%MIX+ P	56.2^{b} (0.9)	2.3^{ghi} (0.1)	0.4^{nop} (0.0)	0.2^{qr} (0.0)
	30%MIX+ UP	38.5^{bcd} (0.4)	1.5^{ij} (0.1)	0.3^{opqr} (0.0)	*
	SAND+ P	33.9^{cde} (0.9)	0.8^{kl} (0.0)	0.1^{st} (0.0)	*
	SAND+ UP	21.2^{e} (0.7)	0.5^{lmn} (0.0)	0.1^{t} (0.0)	*
S-24	30%GC+ P	111.9^{a} (0.9)	4.2^{f} (0.3)	0.9^{k} (0.0)	0.4^{mno} (0.0)
	30%GC+UP	56.3^{b} (0.7)	2.8^{fgh} (0.1)	0.7^{klm} (0.0)	0.3^{pqr} (0.0)
	30%MIX+ P	56.2^{b} (0.6)	2.2^{ghi} (0.1)	0.4^{mno} (0.0)	0.3^{pqr} (0.0)
	30%MIX+ UP	53.6^{b} (0.6)	1.9^{hi} (0.0)	0.3^{nopq} (0.0)	*
	SAND+ P	39.8^{bcd} (1.0)	1.0^{jk} (0.0)	0.2^{rs} (0.0)	*
	SAND+ UP	35.4^{de} (0.3)	0.7^{klm} (0.0)	0.1^{t} (0.0)	*

In both wheat cultivars, the K^+: Na^+ ratio of seedlings obtained from primed seeds sown in 30% GC was significantly higher than that of primed seeds sown either in 30% mix or in sand at all NaCl concentrations. Furthermore, K^+: Na^+ ratio of primed seeds sown in 30% mix was significantly greater than that of primed seeds sown in sand at all NaCl concentrations except with cv. S-24 in 30% GC at 0 mM where the difference was not significant. The K^+: Na^+ ratio of unprimed seeds of both cultivars sown in 30% GC was significantly greater than those sown in sand at all NaCl concentrations. Moreover, K^+: Na^+ ratio in unprimed seeds grown in 30% GC was significantly higher than those sown in 30% mix in some treatments, with cv. Slambo at 100 and 200 mM, and with cv. S-24 at 200 mM. In addition, the result of

K^+: Na^+ ratio showed that there was no significant difference between both cultivars under all stress levels.

Table 5.31. Summary of the effect of the combination of priming and compost on wheat cultivars under salt satress.

Cultivar	Treatment	NaCl	E%	ER	MET	Length		Fresh Weight		Dry Weight		Seedling Ion Content					
						S	R	S	R	S	R	Ca^{2+}	K^+	Na^+	Mg^{2+}	Ca^{2+}:Na^+	K^+:Na^+
Slambo	P +30%GC	0		✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
		100	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		200	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
		300	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	UP +30%GC	0						✓	✓	✓	✓	✓	✓		✓	✓	✓
		100		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		200	✓	✓	✓	✓	✓	✓		✓		✓	✓		✓	✓	✓
		300	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	P +30%mix	0				✓		✓	✓	✓	✓	✓	✓			✓	✓
		100	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
		200	✓	✓	✓	✓	✓					✓				✓	✓
		300	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	UP +30%mix	0								✓		✓				✓	✓
		100		✓	✓		✓	✓				✓				✓	✓
		200	✓		✓	✓	✓	✓								✓	✓
		300															
S-24	P +30%GC	0	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		100	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		200	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
		300	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	UP +30%GC	0					✓	✓			✓	✓	✓			✓	✓
		100		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
		200	✓	✓	✓	✓	✓	✓		✓		✓	✓			✓	✓
		300	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	P +30%mix	0				✓	✓	✓	✓	✓	✓	✓				✓	✓
		100				✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
		200	✓	✓	✓	✓	✓									✓	✓
		300	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	UP +30%mix	0					✓	✓				✓					✓
		100					✓			✓	✓	✓				✓	✓
		200				✓	✓									✓	✓
		300															

S = shoot.
R = root.
✓ = significant effect compared to control (unprimed seeds in sand)

5.4. Discussion.

5.4.1. The Effect of the combination ofpriming and compost on emergence andearly seedlingestablishment

The combination of priming and 30% GC proved to be the most effective in inducing salt tolerance in both cultivars followed by priming and 30% mix compared to the control as indicated by E%, ER, MET, shoot and root length, fresh and dry weight of shoots and roots as well as enhanced seedling ion content. In regard to the performance of both cultivars, they responded to salinity stress in the same manner, and there was no clear difference between cv. S-24 and cv. Slambo cultivars.

It has been widely reported that salinity has a negative effect on final E% of crops (Ghiyasi *et al.* 2008; Ahmadi, Emam, and Pessarakli 2009; Bhutta 2011). A decrease in the E% of wheat has been reported by Akbari, Sanavy and Yousefzadeh (2007), Haidarizadeh and Zarei (2009), Sayar *et al*. (2010a), and Ashraf, Ashraf, and Ali (2010). Moreover, the harmful effect of salinity has also been observed on the ER in many studies including El-Dardiry (2007), Akbarimoghaddam *et al*. (2011), and Benderradji *et al*. (2011). Many researchers have shown that an increase in salt level in growth medium leads to a significant reduction in ER of wheat (*Triticum aestivum* L.) (Rahman *et al*. 2008; Datta *et al*. 2009). Furthermore, the uniformity of field emergence of seedlings is one of the most important pre-requisites to enhance the quality and yield of annual crops (Golezani *et al*. 2010a). However, salinity has also been reported to induce an adverse effect on the MET (Patade, Bhargava, and Suprasanna 2009; Bajehbaj 2010; Akbarimoghaddam *et al*. 2011). Increasing of MET of wheat seeds has also been reported by Afzal *et al*. (2007b), Afzal *et al*. (2008), Rahman *et al*. (2008), Khayatnezhad *et al*. (2010), and Homayoun (2011).

The effect of salinity on the E%, ER and MET has been attributed to the decrease in soil osmotic potential which limits the water uptake and nutrient absorbtion for embryo expansion

due to the increased salt accumulation around the root zone (Rafiq *et al*. 2006; Rahman *et al.* 2008; Leithy, Gaballah, and Gomaa 2009; Sayar *et al*. 2010b). In addition, such an effect could also be attributed to the high accumulation of Na^+ and Cl^- ions in the seeds which causes ion toxicity and then germination inhibition (Sosa *et al*. 2005; Eleiwa, Bafeel and Ibrahim 2011).

In the present study, the E% of cv. S-24 was improved significantly at 0, 100, 200 and 300 mM NaCl as compared to the control when the combination between priming and 30% GC was applied and at 100, 200 and 300 mM with the combination between priming and 30% mix. With cv. Slambo, the E% was also improved significantly at 100, 200 and 300 mM NaCl when the combinations between priming and 30% GC, and priming and 30% mix were applied. In addition, the ER of both cultivars was significantly enhanced at all NaCl concentrations when primed seeds were sown in 30% GC, and at 100, 200 and 300 mM, and 200 and 300 mM, when primed seeds of cv. Slambo and cv. S-24, respectively, were sown in 30% mix. Moreover, the MET was also significantly improved at all salt concentrations in cv. S-24 and at 100, 200 and 300 mM in cv. Slambo when the combination between priming and 30% GC was applied and at 200 and 300 mM in cv. S-24, and at 100, 200 and 300 mM in cv. Slambo when combination between priming and 30% mix was used.

The better performance of primed seeds grown in 30% GC than in 30% mix is probably due to the increase in the availability of water and the increase of Ca^{2+} concentration in the growth medium. It has been reported that the provision of compost to sandy soil can improve the water holding capacity and reduce the loss of water making it more available for plants (Lawson, Hayatsu, and Nioh 2004; El-Dardiry 2007; Abdel-Mawgoud *et al*. 2010). This can be confirmed by the effect of using compost on the water holding capacity (Table 6.23). Moreover, Jamal *et al*. (2011) reported that pre-sowing seed priming improves the uniformity and rate of seed emergence of crops. Priming has also been reported to improve water uptake

due to its effect on the osmotic potential (Saglam *et al*. 2010). Furthermore, Kaya *et al*. (2006) and Jamil and Rha (2007) claimed that priming treatments increased the plant water uptake by decreasing the seed osmotic potential to the point that allows seeds to absorb water to start germination. This can be supported by the enhancement of seed water uptake by using $CaCl_2$ as a priming treatment (Table 6.25). It has been reported that primed seeds can rapidly imbibe and revive the seed metabolism, consequently improving germination rate and uniformity (Golezani *et al*. 2010c).

Under saline conditions, Ca^{2+} has been claimed to be an important ion for osmotic adjustment (Ashraf 2004). Therefore, the improvement of E%, ER and MET might also be due to the increase of Ca^{2+} accumulation as a result of the application of compost and / or the use of priming treatment. Zaman *et al*. (2005), Faiza *et al*. (2007) and Gobinathan, Murali, and Panneerselvam (2009) reported that the availability of Ca^{2+} alleviates the effect of NaCl stress on the plants. Additionally, it has been reported that seed priming with $CaCl_2$ increases the Ca^{2+} ion content of plants (Farooq, Barsa, and Khan 2007; Afzal *et al*. 2008; and Farooq *et al*. 2010b) which leads to better membrane repair (Afzal *et al*. 2007b) and plays an important role in cell wall integrity and structure (Cramer 2002). This relationship can be confirmed by the effect of seed priming with $CaCl_2$ on the seed ion content (Section 6.6). Furthermore, compost has been reported to improve both physical and chemical conditions of saline soil. It has been reported that compost improves nutrient use efficiency by slowing the release of nutrients and reducing their losses (Smith, Beharee, and Hughes 2001; Nevens and Reheul 2003; Ibrahim *et al*. 2008). Moreover, Lakhdar *et al*. (2008) and Abdel-Mawgoud *et al*. (2010) reported that the application of compost to saline soil is expected to discharge acids that eventually lead to the replacement of exchangeable Na^+ by Ca^{2+}. Bhatt *et al*. (2008) reported that the availability of Ca^{2+} in the growth medium is effective in enhancing the resistance of plants to salt stress. Zaman *et al*. (2005), Cramer (2002) and Lakhdar *et al*.

(2008) also highlight that the presence of Ca^{2+}reduces the uptake of Na^{+} and consequently improves the selectivity of K^{+}: Na^{+} ratio which is associated with salt tolerance. This can be supported by the chemical analysis of compost which showed that Ca^{2+} content in GC was significantly higher than in cow compost (Table 4.1).

In the present study, growth parameters were reduced in all the treatments as a result of high salt concentration in the growth medium. Rahman *et al.* (2008), Sayar *et al*. (2010a), Abdel-Mawgoud *et al*. (2010), and Eleiwa, Bafeel, and Ibrahim (2011) attributed the reduction in plant growth parameters such as shoot and root length, fresh and dry weight of shoots and roots by salinity to the inhibition of water absorption by seedlings or of mineral inbalance and / or inhibition of seed reserve mobilization (Sayar *et al*. 2010a). Furthermore, it has also been reported that salinity affects the growth of seedlings by slowing or decreasing mobilization of available reserves, modification of plant cell wall metabolic activities thus suspending cell division and elasticity, and injuring hypocotyls (Naeem and Muhammad 2006; Homayoun 2011). In addition, high accumulation of Na^{+} and / or Cl^{-} in the plant tissue due to excess salts in the rooting zone has also been claimed to cause toxicity or nutrient imbalance (Munns and Tester 2008; Lakhdar *et al*. 2008; Karimi *et al*. 2009). Afzal *et al*. (2006a) and Datta *et al*. (2009) also attributed growth reduction to the toxic effect of Na^{+} and / or Cl^{-}.

The results of this study showed that in both wheat cultivars, the application of the combination of priming and compost significantly improved the growth parameters under stressed conditions as compared to the control, For instance the shoot and root length obtained from seeds treated by priming and grown in 30% GC or exposed to priming and 30% mix was significantly higher than those of seeds sown in sand at all NaCl concentrations. Furthermore, in both wheat cultivars, shoots and roots of seedlings obtained from the combination between priming and 30% GC was significantly higher than those

obtained from the combination between priming and 30% mix. Moreover, the performance of cv. S-24 was better than cv. Slambo in some cases especially at 300 mM of NaCl. Beneficial effects of priming have been widely reported. For instance, Basra *et al*. (2005) found that shoots of wheat obtained from seeds subjected to priming treatment with $CaCl_2$ were significantly longer than with unprimed seeds. Similarly, Salehzade *et al*. (2009) observed that the use of priming seed treatments increased the length of shoots and roots of wheat significantly as compared with unprimed seeds. However, provision of compost has also been found to be effective in alleviating the harmful effect of salinity on growth. Additionally, Ibrahim *et al*. (2008) studied the effect of the application of greenwaste compost on the growth of wheat, and demonstrated that compost significantly increased the plant height, number of tillers, spike length compared to untreated control. Furthermore, in both wheat cultivars, fresh and dry weight of shoots and roots obtained from seeds subjected to priming and 30% GC was significantly higher than with those seedlings grown as control at all NaCl concentrations. In addition, the fresh and dry weight of shoots and roots were significantly greater in seedlings from the combination between priming and 30% GC than in the seedlings from the combination between priming and 30% mix except with cv. Slambo in fresh and dry weight of roots at 200 mM of NaCl. Moreover, the performance of cv. S-24 under all NaCl concentration was better than cv. Slambo even though the difference between them was not significant in many cases.

This improvement in the growth parameters is probably due to the enhancement of metabolic activities or the improvement of the rate of cell wall division which drives seedling growth enhancement (Afzal *et al*. 2006a; Rafiq *et al*. 2006; Afzal *et al*. 2008). Afzal *et al*. (2007b) studied the effects of priming with 50 mM of $CaCl_2$ on the growth of wheat, and suggested that the enhancement in growth parameters is probably due to the improvement in embryo cell division rate. However, Ahmad *et al*. (2008) and Ibrahim *et al*. (2008) reported

that the improvement in growth may be due to the enhanced availability of water and nutrients which are efficiently utilized by seedlings causing better growth. It has been reported that the growth of plants is often positively correlated with the availability of nutrients (Lakhdar *et al*. 2008). It has also been reported that the use of organic materials such as compost improves the water holding capacity and nutrient use efficiency and enhances plant growth (Abdel-Mawgoud *et al*. 2010). This can be supported by the ion content of compost and by the effect of compost on the water holding capacity. Additionally, priming has been reported to positively affect nutrient uptake by plants (Afzal *et al*. 2008) and increase the water uptake of seeds (Jamil and Rha 2007). Afzal *et al*. (2008) reported that pre-sowing seed treatments enhanced the ion uptake in wheat in stressed conditions through which salinity tolerance is enhanced.

5.4.2. The Effect of the Combination between Compost and Priming on the Seedling Na^+, Ca^{2+}, K^+ and Mg^{2+} Concentrations

High salt (NaCl) uptake competes with the uptake of other nutrient ions, especially K^+, leading to K^+ deficiency. Increased treatment of NaCl increases the concentrations of Na^+ and Cl^- and decreases the concentrations of Ca^{2+}, K^+, and Mg^{2+} in plant tissues (Parida and Das 2004, Farhoudi and Sharifzadeh 2006).

Seedling Na^+ Content

Na^+ concentration in seedling tissues was significantly affected at different salt stress levels. Na^+ seedling content increased with increasing NaCl level in the growth medium in both wheat cultivars. This increase of seedling Na^+ content has been reported by Al-Khateeb (2006), Raza *et al*. (2007), Dkhil and Denden (2010), and Qin *et al*. (2010). Ali *et al*. (1999) reported that the increase in seedling Na^+ concentration was due to an elevated concentration

of Na^+ in the root medium, which ultimately resulted in the increased uptake of Na^+ by plants. Moreover, Dkhil and Denden (2010) related this increase in Na^+ concentration to the effect of competition between Na^+ and other ions on the binding sites of the plant. Decreased Na^+ concentration at 100 mM of salinity indicates either the ability of the plant to exclude Na^+ or the ability to make an osmotic adjustment. While at 200 mM the increase in Na^+ concentration indicates the inability of the plant to exclude Na^+ or the need of the plant to absorb more salts in order to adjust its osmotic potential. Moreover, it has been reported that plants exposed to high salinity levels can accumulate high levels of inorganic salts including Na^+ and Cl^- in their tissues in order to adjust their internal osmotic potential to the point that allows them to absorb sufficient amounts of water (Ashraf 2004, Flowers and Flowers 2005, Flowers, Galal, and Bromham 2010). Furthermore, Parida and Das (2004) reported that *A. pseudoalhagi* (a leguminous plant) continued to grow at 200 mM of NaCl even though the leaf Na^+ content increased to 45 times that of the control.

Seedling Ca^{2+} Content

Ca^{2+} is an important cation for the growth of plants grown in normal and saline conditions. Insufficient concentration of Ca^{2+} can reduce crop quality and productivity. Ca^{2+} is an essential element for the maintenance of membrane integrity and the regulation of ion transport (Rehman *et al*. 2000, Cramer 2002, Gobinathan, Murali and Panneerselvam 2009). Moreover, the need for Ca^{2+} is greater with increased salinity stress in the growth medium. Gobinathan, Murali and Panneerselvam (2009) mentioned that one possible approach to alleviating the effect of NaCl stress on crop productivity is through the addition of calcium supplements to irrigation in the case of salt stress. It has been reported that the increase of Ca^{2+} concentration alleviates the negative effect of NaCl stress by plants decreasing their uptake of Na^+ (Rehman *et al*. 2000, Shaikh *et al*. 2007). Moreover, Al-Khateeb (2006)

reported that the addition of Ca^{2+} ameliorated the shoot growth and root elongation of plants under saline stresses and reduced leakage of membranes. In addition, Summart *et al*. (2010) reported that Ca^{2+} and K^{+} are the most important contributors to osmotic adjustment under salt stress conditions in many plant species. Niazi *et al*. (2007) and Zaman *et al*. (2005) claimed that increased level of Ca^{2+} in the growth medium reduced the osmotic effects around the root zone. Moreover, it has been reported that the Ca^{2+}: Na^{+} ratio in the plant is used considerably in salt stress studies (Gence, Tester, and McDonald 2009).

In general with the increase in NaCl concentrations, calcium ion accumulation was decreased. A considerable reduction was recorded in the concentration of Ca^{2+} as a result of the increase of NaCl concentration. The reduction in Ca^{2+} caused by NaCl stress has been reported in a range of plant species for instance with wheat (Afzal *et al*. 2008, Tammam, Alhamd, and Hemeda 2008), rice (Alamgir, Musa, and Ali 2007), and maize (Turan *et al*. 2010). Moreover, the increase in Na^{+} uptake causes nutrient deficiency and consequently decreases the Ca^{2+}: Na^{+} ratio. This reduction in Ca^{2+}: Na^{+} ratio has also been reported by Ashraf (2004), Alamgir, Musa, and Ali (2007), El-Juhany, Aref, and Ahmed (2008), and Khorshidi, Yarnia, and Hassanpanah (2009). Al-Khateeb (2006) reported that Ca^{2+}: Na^{+} ratio declined significantly with increasing NaCl concentration in Alfalfa seedlings. Naeem and Muhammad (2006) attributed this reduction of Ca^{2+} concentration to the decrease of membrane integrity due to salt stress. Moreover, Carter *et al*. (2005) claimed that decrease in Ca^{2+} in the plant as a result of the increase of salt concentration is due to the reduction in the discriminative capacity of the root membranes. Specifically, it has been reported that the deficiency of Ca^{2+} caused by increased Na^{+} concentration is due to the decline in the ability of the plasma membrane to bind Ca^{2+} (Brown, Pezeshki, and DeLaune 2006).

The application of compost and priming increased the seedling Ca^{2+} concentration and thus increased the Ca^{2+}: Na^{+} ratio. This increase was significant in both cultivars compared

with the control at all NaCl concentrations. This enhancement of Ca^{2+} concentration and Ca^{2+}: Na^{+} ratio is due to the application of the combination of priming and compost. It has been reported that the application of $CaCl_2$ as a priming solution increases the Ca^{2+} content of many plants, as described by, Afzal *et al.* (2008) with wheat, and Farooq *et al*. (2006), Farooq, Barsa, and Khan (2007), Farooq *et al*. (2010b) with rice. Moreover, Sarwar *et al*. (2007) mentioned that compost is a rich source of nutrients. Lawson, Hayatsu and Nioh (2004) and Abdel-Mawgoud *et al*. (2010) reported that the application of compost increased the exchangeable Ca^{2+}. Furthermore, Al-Khateeb (2006) found that the addition of Ca^{2+} to the growth medium significantly increased the Ca^{2+}: Na^{+} ratio in Alfalfa seedlings. Several studies highlight that the resistance of plants to salt stress can be improved by an increase in the availability of Ca^{2+} in the growth medium as a result of decreasing the uptake of Na^{+} (Cramer 2002, Zaman *et al*. 2005, Bhatt *et al*. 2008, and Lakhdar *et al*. 2008).

Seedling K^{+} Content

K^{+} is an important plant nutrient (Rehman *et al*. 2000, Sosa *et al*. 2005). Since salt stress affects plant growth through a water deficit, maintaining the turgor pressure is very important. It has been reported that K^{+} activates the enzymatic activities and controls the opening and closing of stomata (Naeem and Muhammad 2006, Zekri and Obreza 2009). Heidari and Jamshid (2010) claimed that the selective uptake of K^{+} is considered to be one of the most important physiological mechanisms contributing to salt tolerance in many species. Shirazi *et al.* (2005) mentioned that the preservation of sufficient amounts of K^{+} enhanced the salt tolerance of wheat. The results of this study showed that the increase of NaCl level caused a significant reduction in seedling K^{+} concentration across all treatments. The decrease of K^{+} as a result of the increase of NaCl level has been reported in many plant species. For example, with wheat (Ali *et al*. 1999, Royo and Abio 2003, Shirazi *et al*. 2005,

Zaman *et al*. 2005, and Othman *et al*. 2006), and with alfalfa (Al-Khateeb 2006). According to Shirazi *et al*. (2005), Patel *et al*. (2010), and Dkhil and Denden (2010), the reduction of K^+ content in plants might be attributed to the effect of competition between Na^+ and K^+ ions on the absorptive sites of plants. Moreover, Anwar *et al*. (2011) reported that Na^+ can exert toxic effect on plants by interfering with the uptake of other nutrient ions, especially K^+ leading to nutrient ion deficiency. Furthermore, the increase in NaCl concentrations significantly affected the K^+: Na^+ ratio. Ramezani, Sepanlou, and Badi (2011) reported that the increase of NaCl concentration in the growth medium decreased uptake of K^+ ions and consequently decreased the K^+: Na^+ ratio. The reduction in K^+: Na^+ ratio can be attributed to the fact that Na^+ causes a disturbance in the ion balance in plant due to an increase in the absorption of Na^+ ion (Summart *et al*. 2010). This reduction in K^+: Na^+ ratio in wheat cultivars has also been reported by Zheng *et al*. (2008), Ragab, Hellal, and El-Hady (2008), Jamal *et al*. (2011), and Salama, Mansour, and Hassan (2011). Ghogdi, Izadi, and Borzouei (2012) studied the effect of salinity on four different wheat cultivars and they reported that the increase in NaCl level reduced the K^+: Na^+ ratio in these cultivars.

The combination of priming and compost treatments had a positive effect on K^+ seedling content. K^+ content in seedlings of both wheat cultivars was significantly higher than the control at all NaCl concentraions. This improvement in K^+ concentration is probably due to the application of compost as a nutrient supplier especially K^+ and Ca^{2+} and / or due to the increase of Ca^{2+} seedling content as a result of the application of priming. Furthermore, Al-Khateeb (2006) mentioned that under stressed conditions, the role of Ca^{2+} is associated with both membrane permeability, which might reduce Na^+ absorption by plants as well as increasing the uptake and transport of K^+ in plants. Additionally, Royo and Abio (2003) reported that the harmful influences of salinity in plants by decreasing K^+ uptake can be minimized by adding Ca^{2+}. It has been reported that Ca^{2+} decreased K^+ outflux from plant

tissue, but caused no appreciable reduction in influx of Na^+ or Mg^{2+} into seedlings (Tobe, Li, and Omasa 2004). In addition, K^+: Na^+ ratio of seedlings derived from primed seeds sown in 30% GC was significantly greater than the control followed by 30% mix in both wheat cultivars under all salinity levels. This enhancement in K^+: Na^+ ratio is due to the increase in K^+ and reduction in Na^+ concentrations in the seedling. Furthermore, it has been reported that Ca^{2+} decreases the toxic effects of Na^+, most probably by enhancing the K^+: Na^+ selectivity which is associated with salt tolerance (Cramer 2002, Shaikh *et al*. 2007, Lakhdar *et al*. 2008).

Seedling Mg^{2+} Content

Mg^{2+} has important physiological and molecular roles in plants such as enzyme activation and in chlorophyll molecules (El-Metwally *et al*. 2010). It has been reported that 15 to 30% of Mg^{2+} in plants is associated with the chlorophyll molecules (El-Metwally *et al*. 2010).

The results showed that seedling Mg^{2+} content was negatively affected by the increase of NaCl level. Mg^{2+} concentration decreased as salinity level increased especially at high NaCl concentration. The effect of NaCl concentration on Mg^{2+} has been reported by Tammam, Alhamd, and Hemeda (2008), and Heidari and Jamshid (2010). As compared with control, the combination of priming and compost increased Mg^{2+} seedling content in both wheat cultivars. Mg^{2+} concentration was significantly higher in seedlings derived from the combination of priming and 30% GC than in seedlings obtained from seeds sown in sand at all NaCl concentrations. This enhancement in Mg^{2+} concentration is probably due to the application of compost and / or due to the application of priming. Abdel-Mawgoud *et al*. (2010) reported that compost application has been shown to positively affect the nutrient content of soil. Furthermore, Naeem and Muhammad (2006) mentioned that priming increased the Mg^{2+} plant content under salt stress.

5.5. Conclusion

It can be concluded that salinity stress decreased plant growth in this experiment. However, the application of the combination of priming and compost was able to alleviate the inhibitory effects of salinity on the seedling growth of both wheat cultivars. The enhancement was shown in almost all measured parameters (E %, ER, MET, shoot and root length, fresh and dry weight of shoots and roots, and seedling ion content). In both wheat cultivars, in saline conditions, seedling emergence and establishment of primed seeds showed better enhancement when the seeds were grown in 30% GC followed by 30% mix. This improvement might be explained by two factors: the increase in the availability of Ca^{2+} due to the application of priming and compost, and the improvement in the availability of water for the plant as affected by both techniques. Thus the effect of priming and compost on the Ca^{2+} concentration and availability of water was tested through a series of experiments outlined in the following chapter.

Chapter 6

Determination of the mechanism of action of compost and priming

6.1. Introduction

The application of an amendment such as compost and the application of a priming solution such as $CaCl_2$ can alleviate the negative effect of the increase of salt concentration in the growth medium by increasing water availability and the concentration of Ca^{2+} (Afzal *et al*. 2008; Farooq *et al*. 2010b). Previous experiments as part of this research showed enhanced germination and growth of the two wheat cultivars under NaCl stress due to the application of compost and priming. On the basis of this work and the grounding in the literature it is hypothesized that improvements in growth of wheat seedlings under salinity stress through priming with $CaCl_2$ and amendment of the growth medium with compost is a result of five key mechanisms:-

1. Provision of Ca^{2+} by compost improves the uptake of other beneficial ions.
2. Improved water availability through the greater water holding capacity provided by compost.
3. Priming with $CaCl_2$ improves the seed water status under NaCl stress.
4. Provision of Ca^{2+} by priming improves membrane integrity and enhances the seed uptake of important ions under NaCl stress.
5. Provision of Ca^{2+} by priming improves the osmotic adjustment of seed.

This chapter therefore summarises the experiments undertaken to test these five hypotheses.

6.2. Determination of the key ion in compost that is responsible for the improvement in the growth of wheat cultivars under salt stress

Ca^{2+} addition has been found to improve the response of several crops to salt stress including wheat, barley and maize (Cramer 2002). It has therefore, been hypothesized that the increase of Ca^{2+} level can protect the cell membrane from the negative effect of salt stress (Cramer 2002, Gobinathan, Murali and Panneerselvam 2009). It has also been reported that one possible approach to alleviating the effect of salinity on crop productivity is through the addition of calcium supplements (Gobinathan, Murali, and Panneerselvam 2009). In addition, K^+ has also been reported to be effective in maintaining performance in wheat (Cuin *et al.* 2008) and barley (Chen, Pottosin, and Cuin 2007) under salt stress. Therefore, providing an artificial supply of certain key ions is claimed to be effective in alleviating the salt stress.

The aim of this experiment was to determine the effective element of 30% compost that improves the growth on the two tested wheat cultivars under saline conditions.

6.2.1. Material and Methods

13 mm pots were filled with 1 kg of sand. To prevent the sand falling out from the bottom a filter paper was placed at the bottom of each pot. Twenty seeds of cv. S-24 and cv. Slambo were sown in each pot separately. Ca^{2+}, Mg^{2+}, and K^+ were added separately and in combination to pots using the same amount that was found in the 30% GC and 30% mix (Table 6.1).

Table 6.1. Metal ion content in 30% GC and 30% mix based on three replicates (g kg^{-1}).

Ion	30% GC	30% MIX
Ca^{2+}	1.85	1.43
K^+	2.21	3.70
Mg^{2+}	0.27	0.26

The amount of each element was calculated as following:

Calculation of Ca^{2+} from $CaCl_2$ as found in 30% GC

The amount of $CaCl_2$ required= $\frac{\text{MW } CaCl_2 \text{ X the amount of } Ca^{2+} \text{ (g)}}{\text{MW } Ca^{2+}}$

Where:

MW of Ca^{2+} = 40.078 g

MW of $CaCl_2$ = 110.984 g

The same calculation was done for the other ions. Table 6.2 shows the amount of chloride salts required for each pot to get the amount of each ion as found in 30% GC and 30% mix.

Table 6.2. The amount of chloride salts required for each pot to meet the concentration of each ion found in each compost treatment.

Compost	$CaCl_2$ (g)	KCl (g)	$MgCl_2$ (g)
30% GC	5.13	6.93	1.08
30% MIX	3.96	11.60	1.02

The combination of ions was calculated by adding the weight of all the ions together. For irrigation, pots were subjected to 0, 100, 200 and 300 mM of NaCl following the same regime used for the experiment undertaken in Chapter 5.

Ca^{2+}, Mg^{2+}, K^+, Ca^{2+}+ Mg^{2+} + K^+ and control =5 element combination × 2 wheat cultivars × 4 NaCl concentrations = 40 treatments × 5 replicates = 200 pots.

The experiment was arranged in a completely randomized design. E%, ER and MET were determined five weeks after sowing. The seedlings were harvested and dry and fresh weight of roots and shoots as well as the length of shoots and roots were measured for each pot as outlined in Chapter 3.

The treatments were considered as following:

T1 = Sand + the same amount of Ca^{2+} as found in 30% GC by application $CaCl_2$.

T2 = Sand + the same amount of Ca^{2+} as found in 30% mix by application $CaCl_2$.

T3 = Sand + the same amount of Mg^{2+} as found in 30% GC by application $MgCl_2$.

T4 = Sand + the same amount of Mg^{2+} as found in 30% mix by application $MgCl_2$

T5 = Sand + the same amount of K^+ as found in 30% GC by application KCl.

T6 = Sand + the same amount of K^+ as found in 30% mix by application KCl.

T7 = Sand + the same amount of Ca^{2+}+ K^+ + Mg^{2+}as found in 30% GC.

T8 = Sand + the same amount of Ca^{2+}+ K^+ + Mg^{2+}as found in 30% mix.

C = Sand

Data were analysed using three way ANOVA. Tukey's test at $p \leq 0.05$ was used to identify significant difference between treatment means. The final emergence percentage was arcsine transformed before analysis.

6.2.2. Results

Emergence Percentage (E%)

Three wayANOVA indicated that all the factors and their combinations had a significant effect ($p < 0.05$) on E% of both wheat cultivars (Table 6.3) except the interaction between cultivar and treatment.

Table 6.3. The significance of interactions between treatments using ANOVA for E%.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Treatment	NS	0.14
Cultivar*NaCl Concentration	S	<0.01
Treatment* NaCl Concentration	S	<0.01
Cultivar*Treatment* NaCl Concentration	S	<0.01

Table 6.4. Effect of different salinity levels on emergence percentage (G%) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in sand under Ca^{2+}, Mg^{2+}, K^{+}, and Ca^{2+}+ Mg^{2+}+ K^{+} supplements (mean values, range in brackets, * = no emergence, n = 5).

Treatment	S-24				Slambo			
	NaCl (mM)							
	0	100	200	300	0	100	200	300
T1	98^{a} (95-100)	$87^{bcdefghi}$ (70-95)	56^{nopqrs} (45-7)	37^{tuvw} (30-45)	95^{abc} (85-100)	$83^{defghijk}$ 75-90)	48^{pqrstu} (30-55)	32^{uvw} (25-40)
T2	97^{ab} (90-100)	$85^{cdefghijk}$ (75-95)	40^{stuv} (30-45)	*	$89^{abcdefg}$ (80-100)	76^{hijklm} (55-90)	33^{uv} (25-45)	*
T3	97^{ab} (90-100)	76^{hijklm} (55-90)	18^{wx} (10-30)	*	$88^{abcdefgh}$ (80-100)	68^{klmnop} (60-75)	4^{y} (0-10)	*
T4	92^{abcde} (45-100)	68^{klmnop} (60-75)	34^{uv} (30-40)	*	95^{abc} (90-100)	60^{mnopqr} (50-65)	2^{y} (0-4)	*
T5	98^{a} (95-100)	$85^{cdefghijk}$ (80-95)	54^{opqrst} (40-80)	*	95^{abc} (90-100)	$78^{ghijklm}$ (75-85)	43^{rstuv} (25-55)	*
T6	95^{abc} (90-100)	72^{ijklmn} (65-80)	32^{uvw} (25-40)	*	$88^{abcdefgh}$ (80-95)	65^{lmnopq} (55-75)	25^{vwx} (15-45)	*
T7	93^{abcd} (85-100)	55^{nopqrs} (40-65)	*	*	$89^{abcdefg}$ (85-95)	46^{qrstuv} (35-55)	*	*
T8	91^{abcdef} (85-100)	43^{rstuv} (35-55)	*	*	$82^{efghijkl}$ (75-90)	41^{stuv} (30-50)	*	*
C	$86^{cdefghij}$ (75-95)	69^{jklmno} (55-75)	23^{vwx} (20-25)	*	$80^{fghijkl}$ (75-85)	59^{mnopqr} (55-65)	13^{xy} (10-15)	*

In this study, the increase of salinity level had a significant effect on the E% (Table 6.4). The reduction in E% as affected by the increase in NaCl concentration was recorded in all treatments and in both wheat cultivars. E% decreased from 98 - 80 % in unstressed conditions to 0 - 56 % at 200 mM of NaCl.

In unstressed conditions, with cv. S-24, the only treatments that enhanced the E% as compared with the control were T1, T2, T3 and T5. Moreover, with cv. Slambo in unstressed conditions, T1, T4, and T5 were the only treatments that gave a higher E% than the control. Furthermore, at 100 mM, the E% of T1 was significantly higher than in all other treatments except with T2, T3 and T5 in both wheat cultivars, and in T6 in cv. S-24. At 200 mM, in both wheat cultivars, the E% with T1 was significantly higher than in all other treatments except with T2 and T5. However, there was no emergence recorded in T7 and T8 at 200 mM for either cultivar. Additionally, T1 was the only treatment that recorded emergence at 300 mM of NaCl in both wheat cultivars.

The difference between cultivars was not clear in all treatments except in T3 and T4 at 200 mM where the E% in cv. S-24 was significantly greater than in cv. Slambo.

Emergence Rate (ER)

Three way ANOVA showed that the emergence rate was affected significantly ($P < 0.05$) by all factors tested (Table 6.5). Moreover, the effects of the interactions on the emergence rate were also significant ($P < 0.05$).

Table 6.5. The significance of interactions between treatments using ANOVA for ER.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Treatment	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Treatment* NaCl Concentration	S	<0.01
Cultivar*Treatment* NaCl Concentration	S	<0.01

The effect of NaCl stress on emergence rate (ER) is shown in Table 6.6. In all investigated treatments and cultivars a significant reduction in the emergence rate was apparent with an increase in NaCl concentration. ER ranged from 0.109 – 0.273 at 0 mM to 0 – 0.154 at 200 mM of NaCl.

The effects of treatments were significant especially in T1 with cv. S-24 where the ER was significantly higher than all other treatments at all NaCl concentrations except in T2 at 100 mM. With cv. Slambo, T1 was also the only treatment that gave a significantly higher ER compared with all other treatments with the exception of T4 at 0 mM, and in T4, T5 andT6 at 100 mM, and in T2 and T5 at 200 mM of NaCl.

There was no significant effect of cultivar on the ER in all investigated treatments except in T1 and T2 at 100 mM and with T3 and T4 at 200 mM where, in both cases, the ER was significantly higher in cv. S-24 than in cv. Slambo.

Table 6.6. Effect of different salinity levels on emergence Rate ($1/T_{50}$) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in sand under Ca^{2+}, Mg^{2+}, K^{+}, and Ca^{2+}+ Mg^{2+}+ K^{+} supplements (mean values, range in brackets, * = no emergence, n = 5).

Treat	S-24				Slambo			
	NaCl (mM)							
	0	100	200	300	0	100	200	300
T1	0.27^{a} (0.24-0.28)	0.20^{cdef} (0.20-0.21)	0.15^{hijkl} (0.1-0.17)	0.09^{pqrst} (0.07-0.11)	0.25^{ab} (0.23-0.29)	0.15^{hijkl} (0.12-0.17)	0.12^{lmnop} (0.11-0.14)	0.08^{tu} (0.08-0.1)
T2	0.22^{bc} (0.20-0.23)	0.17^{fghij} (0.13-0.20)	0.08^{rst} (0.07-0.09)	*	0.20^{cdef} 0.16-0.21)	0.11^{mnopqr} (0.11-0.12)	0.09^{opqrst} (0.09-0.1)	*
T3	0.16^{ghij} (0.14-0.17)	0.11^{mnopqr} (0.10-0.12)	0.08^{rst} (0.07-0.09)	*	0.18^{defgh} (0.15-0.22)	$0.11^{mnopqrs}$ (0.10-0.13)	0.04^{vw} (0.02-0.07)	*
T4	0.20^{cdefg} (0.18-0.23)	0.13^{lmnop} (0.11-0.14)	0.08^{rst} (0.07-0.08)	*	0.22^{bcd} (0.19-0.25)	0.13^{klmnop} (0.12-0.13)	0.01^{x} (0.01-0.05)	*
T5	0.21^{cde} (0.18-0.22)	0.16^{hijk} (0.11-0.17)	0.11^{opqrst} (0.08-0.11)	*	0.18^{efgh} (0.16-0.18)	0.14^{ijklm} (0.12-0.15)	0.1^{opqrst} (0.08-0.12)	*
T6	0.17^{efghij} (0.14-0.18)	0.10^{opqrst} (0.09-0.11)	0.08^{rst} (0.08-0.09)	*	0.18^{efgh} (0.12-0.19)	0.12^{lmnopq} (0.11-0.14)	0.08^{rst} (0.04-0.1)	*
T7	0.18^{efgh} (0.15-0.20)	0.12^{lmnopq} (0.09-0.15)	*	*	0.17^{fghij} (0.13-0.18)	0.09^{pqrst} (0.08-0.10)	*	*
T8	$0.10^{nopqrst}$ (0.09-0.12)	0.08^{st} (0.08-0.09)	*	*	0.13^{klmno} (0.12-0.13)	0.09^{qrst} (0.05-0.11)	*	*
C	0.17^{efghi} (0.14-0.21)	0.10^{opqrst} (0.10-0.11)	0.04^{uvw} (0.04-0.05)	*	0.16^{fghij} (0.11-0.19)	0.08^{rst} (0.06-0.10)	0.01^{wx} (0.01-0.02)	*

Mean Emergence Time (MET)

Three way ANOVA indicated that there was a significant effect ($p < 0.05$) of all factors on MET except for the interaction between cultivar and NaCl concentration where the difference in MET was not significant ($p > 0.05$) (Table 6.7).

The effect of NaCl on the MET was appaered in all the treatments (Table 6.8). The increase in NaCl concentration increased MET. MET ranged from 4.36 – 9.85 days at 0 mM to 0 – 11.87 days at 300 mM. In both wheat cultivars a significant increase in MET was

recordrd for all treatments at 200 mM except with T1 in both cultivars and T3 in cv. Slambo where a significant decrease was not apparent until NaCl concentration increased to 300 mM.

Table 6.7. The significance of interactions between treatments using ANOVA for MET.

Treatment Combination	Significant or not	p
Cultivar	S	0.02
Treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Treatment	S	<0.01
Cultivar*NaCl Concentration	NS	0.35
Treatment* NaCl Concentration	S	<0.01
Cultivar*Treatment* NaCl Concentration	S	<0.01

Table 6.8. Effect of different salinity levels on the mean emergence time (MET) (days) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in sand under Ca^{2+}, Mg^{2+}, K^{+}, and Ca^{2+}+ Mg^{2+}+ K^{+} supplements (mean values, standard errors in brackets, * = no emergence, n = 5).

Treat	S-24				Slambo			
	NaCl (mM)							
	0	100	200	300	0	100	200	300
T1	4.3^{jkl} (0.1)	5.7^{hijkl} (0.2)	$7.2^{efghijk}$ (0.3)	11.4^{bcdef} (0.7)	4.8^{ijkl} (0.1)	$7.2^{efghijk}$ (0.1)	$9.4^{cdefghi}$ (0.6)	11.8^{bcdef} (0.4)
T2	5.2^{hijkl} (0.1)	6.8^{fghijk} (0.1)	12.4^{bcde} (0.1)	*	5.9^{ghijkl} (0.2)	9.2^{defghi} (0.1)	11.3^{bcdef} (0.2)	*
T3	5.8^{ghijkl} (0.6)	8.7^{defghi} (0.6)	11.2^{bcdef} (0.7)	*	$6.4^{fghijkl}$ (0.3)	8.9^{defghi} (1.0)	10.4^{bcdefg} (0.6)	*
T4	5.8^{ghijkl} (0.3)	$8.7^{defghij}$ (0.1)	14.2^{bc} (0.2)	*	5.3^{hijkl} (0.1)	8.9^{defghi} (0.1)	14.5^{bc} (0.5)	*
T5	5.7^{hijkl} (0.1)	$7.5^{efghijk}$ (0.1)	10.1^{cdefgh} (0.4)	*	5.8^{ghijkl} (0.1)	$7.7^{efghijk}$ (0.2)	14.8^{bc} (0.5)	*
T6	$6.5^{fghijkl}$ (0.1)	8.3^{efghij} (0.7)	12.7^{bcde} (0.3)	*	$6.1^{fghijkl}$ (0.1)	9.8^{cdefgh} (0.6)	13.4^{bcd} (0.7)	*
T7	$6.5^{fghijkl}$ (0.3)	9.0^{defghi} (0.5)	*	*	9.6^{cdefgh} (0.2)	10.9^{bcdefg} (0.4)	*	*
T8	9.8^{cdefgh} (0.3)	11.5^{bcdef} (0.7)	*	*	$8.6^{defghij}$ (0.1)	11.2^{bcdef} (0.4)	*	*
C	$6.3^{fghijkl}$ (0.2)	9.0^{defghi} (0.5)	13.5^{bcd} (0.4)	*	6.7^{fghijk} (0.4)	11.8^{bcdef} (0.6)	16.4^{b} (0.2)	*

The effect of treatment on MET was not clear. There was no significant difference between treatments at 0 and 100 mM in either wheat cultivars except between T1 and T8 at 0 and 100 mM with cv. S-24 and T1 and T7 at 0 mM with cv. Slambo where the MET in T1 was

significantly lower in both cases. At 200 mM, T1 was the only treatment that had significantly lower MET compared to C (control) in both cultivars, while at 300 mM T1 also was the only treatment that recorded emergence. However, there was no effect of cultivar on MET in all treatments at all NaCl concentrations.

Shoot and Root Length

Shoot Length

Three way ANOVA showed that the effect of all the factors and their combinations on the shoot length was significant ($p < 0.05$) (Table 6.9).

Table 6.9. The significance of interactions between treatments using ANOVA for shoot length.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Treatment	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Treatment* NaCl Concentration	S	<0.01
Cultivar*Treatment* NaCl Concentration	S	<0.01

The increase in salinity level negatively affected shoot length in both wheat cultivars. In all treatments, there was a significant decrease in shoot length from 7.84 - 24.34 cm in unstressed conditions to 2.17- 6.7 cm at 200 mM NaCl to 1.4–2.7 cm at 300 mM (Table 6.10).

The results showed that there was a significant effect of treatments on shoot length. In both wheat cultivars, T1 showed significantly greater shoot length than in all other treatments under all NaCl concentrations except with T5 at 200 mM in cv. S-24 and with T2 at 100 mM in cv. Slambo. However, several treatments had a significantly lower shoot length than controls at 0 and 100 mM. For cv. S-24 these included T4, T7 and T8 at 0 mM, and T3, T4,

T5, T6, T7 and T8 at 100 mM. For cv. Slambo treatments with shorter shoot length than controls were T4, T7 and T8 at 0 mM, and T4, T6, T7, and T8 at 100 mM.

Table 6.10. Effect of different salinity levels on shoot length (cmplant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in sandunder Ca^{2+}, Mg^{2+}, K^{+}, and Ca^{2+}+ Mg^{2+}+ K^{+} supplements (mean values, standard errors in brackets, * = no emergence, n = 5).

Treat	S-24				Slambo			
	NaCl (mM)							
	0	100	200	300	0	100	200	300
T1	24.3^{a} (0.4)	17.2^{cdef} (0.3)	6.5^{pqrs} (0.5)	2.7^{wxy} (0.5)	22.1^{ab} (0.4)	14.2^{hi} (0.4)	6.7^{pqrs} (0.3)	1.4^{yz} (0.1)
T2	21.4^{b} (0.3)	14.7^{ghi} (0.5)	4.1^{tuvwx} (0.1)	*	17.4^{cde} (0.6)	12.7^{ij} (0.5)	2.4^{xyz} (0.5)	*
T3	17.3^{cdef} (0.6)	10.7^{jklm} (0.4)	3.1^{uvwx} (0.3)	*	15.3^{fgh} (0.8)	7.6^{opqr} (0.3)	3.0^{vwx} (0.1)	*
T4	14.7^{ghi} (0.4)	8.8^{mnop} (0.5)	2.7^{wxy} (0.4)	*	11.7^{jk} (0.6)	5.4^{rstu} (0.7)	2.5^{xyz} (0.1)	*
T5	19.2^{bc} (0.3)	11.4^{jkl} (0.4)	5.1^{stuv} (0.6)	*	15.3^{fgh} (0.2)	9.3^{lmno} (1.0)	5^{stuv} (0.1)	*
T6	17.7^{cde} (0.4)	8.1^{nop} (0.3)	3.6^{tuvwx} (0.4)	*	15^{fghi} (0.1)	5.4^{rstu} (0.3)	2.5^{xyz} (0.2)	*
T7	9.2^{lmno} (0.5)	4.6^{sruvw} (0.2)	*	*	10^{klmn} (0.3)	5.6^{qrst} (0.3)	*	*
T8	8.3^{nop} (0.8)	2.4^{xyz} (0.3)	*	*	7.8^{nopq} (0.6)	2.8^{wxy} (0.1)	*	*
C	18.8^{cd} (0.3)	14.2^{hi} (0.2)	2.1^{yz} (0.1)	*	15.4^{efgh} (0.3)	9.3^{klmno} (0.1)	0.9^{z} (0.0)	*

The effect of cultivar on shoot length was apparent in many treatments especially in low NaCl concentrations (0 and 100 mM) where the shoot length of cv. S-24 was significantly higher than cv. Slambo in all treatments except with T7 and T8.

Root Length

Three way ANOVA indicated all factors and their combinations were significant for root length ($p < 0.05$) (Table 6.11).

Table 6.11. The significance of interactions between treatments using ANOVA for root length.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Treatment	S	0.04
Cultivar*NaCl Concentration	S	<0.01
Treatment* NaCl Concentration	S	<0.01
Cultivar*Treatment* NaCl Concentration	S	<0.01

Salinity affected the root length of both cultivars significantly (Table 6.12). The result showed that root length decreased significantly with an increase in NaCl concentration. Across all treatments, the only exceptions were T7 for cv. S-24 and T4 for cv. Slambo, both at 100 mM.

Table 6.12. Effect of different salinity levels on root length (cm plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in sand under Ca^{2+}, Mg^{2+}, K^{+}, and Ca^{2+}+ Mg^{2+}+ K^{+} supplements (mean values, standard errors in brackets, * = no emergence, n = 5).

Treat	S-24				Slambo			
	NaCl (mM)							
	0	100	200	300	0	100	200	300
T1	24.9^{a} (1.3)	15.4^{de} (0.4)	8.6^{jklmno} (0.8)	2.4^{vwx} (0.3)	20.8^{b} (0.3)	15.3^{de} (0.8)	7.8^{klmnopqr} (0.3)	1.9^{wx} (0.3)
T2	20.8^{b} (0.2)	13.3^{defg} (0.5)	6.1^{nopqrs} (0.6)	*	19.4^{bc} (1.1)	12.4^{efghi} (0.5)	6.1^{nopqrs} (0.5)	*
T3	14.7^{de} (1.2)	6.2^{nopqrs} (0.3)	2.6^{vwx} (0.1)	*	10.6^{ghijkl} (0.7)	6.1^{nopqrs} (0.1)	3.4 ^{tuvw} (0.2)	*
T4	11.2^{fghij} (0.9)	5.3^{pqrstu} (0.8)	2.7^{uvwx} (0.6)	*	8.3^{jklmnop} (1.0)	5.2^{pqrstuv} (0.7)	2.3^{vwx} (0.1)	*
T5	14^{def} (0.3)	8.7^{jklmno} (0.4)	5.3^{pqrstu} (0.4)	*	13.2^{defg} (0.4)	9.7^{hijklm} (0.5)	5.1^{pqrstuv} (0.4)	*
T6	14.3^{def} (0.9)	6.0^{nopqrs} (0.1)	3.6^{stuvw} (0.2)	*	10.7^{ghijk} (0.9)	5.9^{opqrst} (0.6)	4.8^{rstuv} (0.2)	*
T7	8.1^{jklmnopq} (0.5)	5.1^{qrstuv} (0.2)	*	*	9.3^{ijklmn} (0.8)	5.3^{pqrstu} (0.3)	*	*
T8	6.7^{mnopqrs} (0.6)	2.1^{vwx} (0.2)	*	*	6.9^{mnopqr} (0.7)	2.4^{vwx} (0.2)	*	*
C	16.1^{cd} (0.6)	7.4^{lmnopqr} (0.6)	2.0^{wx} (0.2)	*	15.7^{d} (0.4)	6.5^{mnopqrs} (0.5)	1.0^{x} (0.1)	*

The root length of T1 was significantly greater than for all other treatments in both cultivars except with T2 at 100 and 200 mM for cv. S-24 and with T2 at 0, 100 and 200 mM, and with T5 and T6 at 200 mM all with cv. Slambo.

The effect of cultivar was limited to unstressed conditions such that the root length of cv. S-24 was significantly greater than in cv. Slambo for T1, T3 and T6 at 0 mM of NaCl.

Shoot and Root Fresh Weight

Shoot Fresh Weight

Three way ANOVA indicated that all factors and their combinations had a significant effect ($p < 0.05$) on the shoot fresh weight (Table 6.13).

Table 6.13. The significance of interactions between treatments using ANOVA for shoot fresh weight.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Treatment	S	0.04
Cultivar*NaCl Concentration	S	<0.01
Treatment* NaCl Concentration	S	<0.01
Cultivar*Treatment* NaCl Concentration	S	<0.01

The shoot fresh weight of both cultivars was affected by the increase in NaCl concentration (Table 6.14). Shoot fresh weight decreased significantly with increased salinity in all treatments except in cv. S-24 with T1 at 300 mM relative to 200 mM, with T6 at 200 mM relative to 100 mM, and in cv. Slambo with T1 at 300 mM relative to 200 mM and with T3, T4, T5 and T6 at 200 mM relative to 100 mM.

The effect of treatment was significant in many cases. At 0 and 100 mM of NaCl, the shoot fresh weight with T1 was significantly higher than in all other treatments except with

T2 and C at 100 mM in cv. S-24, and with T2, T3 and C at 0 mM, and with T2 at 100 mM in cv. Slambo. Moreover, there was no significant effect of treatment on the shoot fresh weight at 200 mM NaCl in both cultivars. However, several treatments had a significantly lower shoot fresh weight than C, specifically T7 and T8 in both cultivars at 0 and 100 mM and T3 and T4 in cv. S-24 at 100 mM.

Table 6.14. Effect of different salinity levels on shoot fresh weight ($gplant^{-1}$) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in sand under Ca^{2+}, Mg^{2+}, K^{+}, and Ca^{2+}+ Mg^{2+}+ K^{+} supplements (mean values, standard errors in brackets, * = no emergence, n = 5).

Treat	S-24				Slambo			
	NaCl (mM)							
	0	100	200	300	0	100	200	300
T1	4.87^{a} (0.41)	2.00^{ghi} (0.88)	0.52^{nopqrs} (0.07)	0.09^{pqrs} (0.01)	3.49^{bc} (0.10)	1.82^{hi} (0.13)	0.49^{nopqrs} (0.11)	0.06^{rs} (0.01)
T2	4.08^{b} (0.09)	1.84^{hi} (0.10)	0.42^{nopqrs} (0.01)	*	3.38^{cd} (0.16)	1.72^{ij} (0.18)	0.27^{opqrs} (0.02)	*
T3	3.12^{cde} (0.06)	0.81^{mno} (0.06)	0.08^{qrs} (0.01)	*	2.96^{cdef} (0.15)	0.56^{mnopqr} (0.15)	0.13^{pqrs} (0.03)	*
T4	2.79^{def} (0.15)	0.76^{mno} (0.11)	0.04^{rs} (0.00)	*	2.44^{fgh} (0.13)	0.69^{mnopq} (0.07)	0.07^{qrs} (0.01)	*
T5	3.55^{bc} (0.12)	1.18^{ijklm} (0.11)	0.42^{nopqrs} (0.09)	*	2.74^{ef} (0.16)	0.98^{klmn} (0.07)	0.47^{nopqrs} (0.03)	*
T6	2.80^{def} (0.26)	0.80^{mno} (0.08)	0.28^{opqrs} (0.05)	*	2.60^{efg} (0.04)	0.71^{mnop} (0.06)	0.22^{opqrs} (0.02)	*
T7	1.86^{hi} (0.21)	0.29^{opqrs} (0.01)	*	*	1.47^{ijkl} (0.09)	0.28^{opqrs} (0.01)	*	*
T8	1.68^{ij} (0.02)	0.12^{pqrs} (0.03)	*	*	1.01^{klmn} (0.12)	0.11^{pqrs} (0.03)	*	*
C	3.21^{cde} (0.26)	1.60^{ijk} (0.10)	0.2^{opqrs} (0.03)	*	3.20^{cde} (0.26)	0.92^{lmn} (0.03)	0.01^{s} (0.00)	*

A significant effect of cultivar on shoot fresh weight was found at 0 mM with T1, T2, T5 and T8. In all these treatments, shoot fresh weight in cv. S-24 was significantly higher than in cv. Slambo.

Root Fresh Weight

Three way ANOVA showed that all factors had a significant effect ($p < 0.05$) on the shoot fresh weight except the interaction between cultivar and treatment (Table 6.15).

Table 6.15. The significance of interactions between treatments using ANOVA for root fresh weight.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Treatment	NS	0.08
Cultivar*NaCl Concentration	S	<0.01
Treatment* NaCl Concentration	S	<0.01
Cultivar*Treatment* NaCl Concentration	S	<0.01

Table 6.16. Effect of different salinity levels on mean root fresh weight (g plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in sand under Ca^{2+}, Mg^{2+}, K^{+}, and Ca^{2+}+ Mg^{2+}+ K^{+} supplements (mean values, standard errors in brackets, * = no emergence, n = 5).

Treat	S-24				Slambo			
	NaCl (mM)							
	0	100	200	300	0	100	200	300
T1	6.5^{a} (0.6)	2.8^{fgh} (0.2)	2.0^{hijklmno} (0.3)	0.5^{pqrst} (0.1)	5.4^{abc} (0.2)	3.0^{fgh} (0.1)	1.1^{nopqrst} (0.1)	0.3^{rst} (0.0)
T2	5.9^{ab} (0.2)	2.7^{fghi} (0.2)	1.1^{opqrst} (0.2)	*	4.8^{bcd} (0.1)	2.6^{ghij} (0.2)	0.9^{opqrst} (0.2)	*
T3	4.8^{bcd} (0.2)	2.5^{ghijklm} (0.2)	0.2^{rst} (0.0)	*	4.8^{bcd} (0.3)	1.5^{klmnopq} (0.2)	0.2st (0.0)	*
T4	4.4^{cde} (0.6)	1.6^{ijklmnop} (0.2)	0.2^{t} (0.0)	*	4.2^{de} (0.1)	1.4^{mnopqrs} (0.1)	0.3^{rst} (0.1)	*
T5	4.3^{de} (0.2)	2.6^{ghijkl} (0.2)	1.6^{ijklmnopq} (0.3)	*	4.8^{bcd} (0.2)	2.5^{ghijklm} (0.1)	1.0^{opqrst} (0.1)	*
T6	3.3^{efg} (0.2)	1.6^{ijklmnop} (0.1)	0.9^{opqrst} (0.2)	*	3.3^{efg} (0.1)	1.4^{lmnopqr} (0.2)	0.9^{opqrst} (0.1)	*
T7	2.3^{ghijklmn} (0.3)	1.5^{ijklmnopq} (0.1)	*	*	2.1^{hijklmno} (0.1)	1.0^{opqrst} (0.2)	*	*
T8	2.6^{ghijk} (0.1)	0.5^{pqrst} (0.1)	*	*	1.5^{jklmnopq} (0.1)	0.7^{pqrst} (0.0)	*	*
C	3.9^{def} (0.2)	1.6^{ijklmnop} (0.1)	0.4^{qrst} (0.0)	*	2.8^{fgh} (0.1)	0.8^{pqrst} (0.0)	0.1^{t} (0.0)	*

The increase of NaCl concentration negatively affected the root fresh weight of both cultivars (Table 6.16). Root fresh weight ranged from 1.53 – 6.52 g at 0 mM to 0.32 – 0.58 g at 300 mM. A significant decrease in the root fresh weight was observed between 0 and 100 mM of NaCl in almost all the treatments except in cv. S-24 with T7, and in cv. Slambo with T7 and T8. However, in some treatments there was no significant difference between 100 and 200 mM of NaCl, such as with T1, T5 and T6 with cv. S-24, and with T4 and T6 with cv. Slambo.

Several significant treatment effects were apparent. T1 was significantly greater than all other treatments except in cv. S-24 with T2 at 0 mM, T2,T3 and T5 at 100 mM, andT2, T5 and T6 at 200 mM, and in cv. Slambo with T2, T3 and T5 at 0 mM, T2 and T5 at 100 mM, and T2, T3, T4, T5, T6 and C at 200 mM. However, some treatments had a significantly lower root fresh weight than C such as cv. S-24 with T7 and T8, and cv. Slambo with T8. There was no effect of cultivar on root fresh weight across all the treatments.

Shoot and Root dry weight

Shoot Dry Weight

Three way ANOVA showed that all individual factors and the interactions between them had a significant ($p < 0.05$) effect on the shoot dry weight, except the overall interaction (Table 6.17).

Table 6.17. The significance of interactions between treatments using ANOVA for shoot dry weight.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Treatment	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Treatment* NaCl Concentration	S	<0.01
Cultivar*Treatment* NaCl Concentration	NS	0.16

Table 6.18. Effect of different salinity levels on shoot dry weight (g plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in sand under Ca^{2+}, Mg^{2+}, K^{+}, and Ca^{2+}+ Mg^{2+}+ K^{+} supplements (mean values, standard errors in brackets, * = no emergence, n = 5).

Treat	S-24				Slambo			
	NaCl (mM)							
	0	100	200	300	0	100	200	300
T1	1.15^{a} (0.20)	0.57^{bcde} (0.02)	0.15^{ijklmn} (0.01)	0.08^{klmn} (0.04)	0.69^{bcd} (0.03)	0.33^{fghi} (0.03)	0.10^{jklmn} (0.01)	0.03^{mn} (0.00)
T2	0.74^{bc} (0.02)	0.33^{fghi} (0.04)	0.09^{jklmn} (0.01)	*	0.63^{bcde} (0.03)	0.24^{ijklm} (0.01)	0.07^{klmn} (0.00)	*
T3	0.63^{bcde} (0.01)	0.12^{jklmn} (0.01)	0.04^{lmn} (0.02)	*	0.55^{cde} (0.02)	0.11^{jklmn} (0.02)	0.06^{klmn} (0.01)	*
T4	0.50^{defg} (0.01)	0.07^{klmn} (0.01)	0.02^{n} (0.03)	*	0.45^{efgh} (0.04)	0.10^{jklmn} (0.00)	0.04^{lmn} (0.01)	*
T5	0.71^{bc} (0.01)	0.22^{ijklmn} (0.01)	0.08^{klmn} (0.01)	*	0.54^{cdef} (0.03)	0.13^{ijklmn} (0.01)	0.09^{jklmn} (0.03)	*
T6	0.55^{cde} (0.04)	0.17^{ijklmn} (0.02)	0.07^{klmn} (0.01)	*	0.48^{defg} (0.01)	0.12^{ijklmn} (0.01)	0.06^{klmn} (0.00)	*
T7	0.30^{ghij} (0.05)	0.08^{klmn} (0.00)	*	*	0.21^{ijklmn} (0.11)	0.08^{klmn} (0.00)	*	*
T8	0.24^{hijkl} (0.01)	0.05^{klmn} (0.01)	*	*	0.16^{ijklmn} (0.01)	0.05^{klmn} (0.01)	*	*
C	0.77^{b} (0.02)	0.25^{hijk} (0.01)	0.09^{klmn} (0.01)	*	0.57^{bcde} (0.03)	0.11^{jklmn} (0.00)	0.02^{n} (0.01)	*

Shoot dry weight was significantly affected by salinity across almost all treatments (Table 6.18). The increase in NaCl concentration led to a decrease in shoot dry weight in both cultivars. With cv. S-24, a significant decrease was found between 0 and 100 mM for all treatments except T8, while with cv. Slambo, a significant reduction was also observed between 0 and 100 mM except with T7 and T8.

Treatment significantly affected shoot dry weight. Shoot dry weight with T1 was significantly higher than C and all other treatments at 0 and 100 mM for cv. S-24. In cv. Slambo, shoot dry weight with T1 was significantly greater than C only at 100 mM. However, in cv. S-24, T4, T6, T7 and T8 had a significantly lower shoot dry weight than C at 0 mM, while in cv. Salmbo T7 and T8 had a significantly lower shoot dry weight than C at 0 mM.

The effect of cultivar on the shoot dry weight was shown in Ca^{2+} in T1 at 0 and 100 mM where shoot dry weight of cv. S-24 seedlings was significantly higher than that of seedlings of cv. Slambo

Root Dry Weight

Three way ANOVA indicated that all factors and intractions had a significant effect on the root dry weight (Table 6.19).

Table 6.19. The significance of interactions between treatments using ANOVA for root dry weight.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Treatment	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Treatment	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Treatment* NaCl Concentration	S	<0.01
Cultivar*Treatment* NaCl Concentration	S	<0.01

The increase in NaCl concentration negatively affected the root dry weight (Table 6.20). However, a significant decrease was not recorded until 200 mM in all treatments in both cultivars except in cv. S-24 with T4 and T8, in cv. Slambo with T1, T3, T4 and C where a significant reduction was recorded at 100 mM.

The root dry weight of T1 was significantly greater than the control at all NaCl concentrations with cv. S-24 and at 0 and 100 mM with cv. Slambo. Furthermore, in cv. S-24 root dry weight with T2 was also significantly higher than C at 0 and 100 mM. However, root dry weight in cv. S-24 with T8 was significantly lower than C at 100 mM.

Table 6.20. Effect of different salinity levels on root dry weight (g plant^{-1}) of seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) sown in sand under Ca^{2+}, Mg^{2+}, K^{+}, and Ca^{2+}+ Mg^{2+}+ K^{+} supplements (mean values, standard errors in brackets, * = no emergence, n = 5).

Treat	S-24				SLAMBO			
	NaCl (mM)							
	0	100	200	300	0	100	200	300
T1	1.4^{a} (0.1)	1.2^{ab} (0.3)	0.6^{efghijk} (0.3)	0.2^{nopqrstu} (0.1)	1.1^{abc} (0.1)	0.6^{efghijklm} (0.3)	0.2^{nopqrstu} (0.0)	0.1^{rstu} (0.1)
T2	1.1^{abc} (0.1)	0.9^{bcde} (0.0)	0.3^{jklmnopqrs} (0.1)	*	0.8^{cdefg} (0.0)	0.5^{fghijklmno} (0.0)	0.2^{opqrstu} (0.0)	*
T3	0.6^{efghij} (0.1)	0.5^{ghijklmno} (0.0)	0.1^{stu} (0.0)	*	0.8^{bcdef} (0.1)	0.2^{mnopqrstu} (0.1)	0.1^{stu} (0.0)	*
T4	0.8^{cdefgh} (0.1)	0.3^{klmnopqrstu} (0.0)	0.1^{stu} (0.0)	*	0.7^{defgh} (0.0)	0.3^{lmnopqrstu} (0.0)	0.1^{pqrstu} (0.0)	*
T5	0.7^{efghi} (0.0)	0.5^{ghijklmno} (0.1)	0.3^{lmnopqrstu} (0.1)	*	0.7^{efghij} (0.0)	0.4^{ijklmnopq} (0.1)	0.2^{nopqrstu} (0.0)	*
T6	0.6^{efghijklm} (0.0)	0.3^{jklmnopqrst} (0.0)	0.2^{nopqrstu} (0.4)	*	0.6^{efghijklm} (0.0)	0.2^{mnopqrstu} (0.1)	0.2^{opqrstu} (0.0)	*
T7	0.5^{hijklmnop} (0.1)	0.3^{klmnopqrstu} (0.0)	*	*	0.4^{ijklmnopqr} (0.0)	0.3^{mnopqrstu} (0.0)	*	*
T8	0.5^{efghijklmn} (0.0)	0.1^{qrstu} (0.0)	*	*	0.3^{lmnopqrstu} (0.0)	0.1^{qrstu} (0.0)	*	*
C	0.7^{efghi} (0.1)	0.5^{hijklmnop} (0.0)	0.1^{qrstu} (0.1)	*	0.6^{efghijkl} (0.0)	0.2^{opqrstu} (0.0)	0.1^{stu} (0.0)	*

The effect of cultivar on the root dry weight was not apparent except with T1 and T2 at 100 mM and with T1 at 200 mM where the root dry weight of seedlings of cv. S-24 was significantly greater than that of seedlings of cv. Slambo.

Table 6.21. Summary of experimental investigation for the key ion in compost for cv. Slambo.

Cultivar	Treatment	NaCl	E%	ER	MET	Length		Fresh Weight		Dry Weight	
						S	**R**	**S**	**R**	**S**	**R**
Slambo	T1 Ca^{2+} in 30% GC	**0**	✓	✓		✓	✓		✓		✓
		100	✓	✓		✓	✓	✓	✓	✓	✓
		200	✓	✓	✓	✓	✓				
		300	✓	✓	✓	✓	✓	✓	✓	✓	✓
	T2 Ca^{2+} in 30% mix	**0**					✓		✓		
		100				✓	✓	✓	✓		
		200	✓	✓			✓				
		300									
	T3 Mg^{2+} in 30% GC	**0**					o		✓		
		100									
		200				✓	✓				
		300									
	T4 Mg^{2+} in 30% mix	**0**	✓	✓		o	o		✓		
		100		✓		o					
		200									
		300									
	T5 K^{+} in 30% GC	**0**	✓						✓		
		100		✓					✓		
		200	✓	✓		✓	✓				
		300									
	T6 K^{+} in 30% mix	**0**					o				
		100	o	✓		o					
		200		✓			✓				
		300									
	T7 (Ca^{2+}+ Mg^{2+}+ K^{+}) in 30% GC	**0**				o	o	o		o	
		100				o		o			
		200									
		300									
	T8 (Ca^{2+}+ Mg^{2+}+ K^{+}) in 30% mix	**0**		o		o	o	o	o	o	
		100				o	o	o			
		200									
		300									

S = shoot.
R = root.
✓ = significant positive effect compared to control
O =significant negative effect compared to control

Table 6.22. Summary of experimental investigation for the key ion in compost for cv. S-24.

Cultivar	Treatment	NaCl	E%	ER	MET	Length		Fresh Weight		Dry Weight	
						S	R	S	R	S	R
S-24	T1 Ca^{2+} in 30% GC	**0**	✓	✓		✓	✓	✓	✓	✓	✓
		100	✓	✓		✓	✓		✓	✓	✓
		200	✓	✓	✓	✓	✓		✓		✓
		300	✓	✓	✓	✓	✓	✓	✓	✓	✓
	T2 Ca^{2+} in 30% mix	**0**	✓	✓		✓	✓	✓	✓		✓
		100		✓			✓				✓
		200		✓		✓	✓				
		300									
	T3 Mg^{2+} in 30% GC	**0**	✓								
		100				o		o			
		200				✓					
		300									
	T4 Mg^{2+} in 30% mix	**0**				o	o			o	
		100				o		o			
		200									
		300									
	T5 K^{+} in 30% GC	**0**	✓								
		100		✓		o					
		200	✓	✓		✓	✓				
		300									
	T6 K^{+} in 30% mix	**0**								o	
		100				o		o			
		200		✓		✓					
		300									
	T7 (Ca^{2+}+ Mg^{2+}+ K^{+}) in 30% GC	**0**				o	o	o	o	o	
		100	o			o		o			
		200									
		300									
	T8 (Ca^{2+}+ Mg^{2+}+ K^{+}) in 30% mix	**0**		o		o	o	o	o	o	
		100	o			o	o	o			o
		200									
		300									

S = shoot.
R = root.
✓ = significant positive effect compared to control
O =significant negative effect compared to control

6.2.3. Discussion

The results of this study showed that E%, ER and MET were negatively affected by the increase in NaCl level in both wheat cultivars. As NaCl level increased, E% and ER significantly decreased, while MET significantly increased in almost all treatments at 200 mM in both cultivars. The results also showed that there was no emergence with T7 and T8 at 200 mM, and this is probably due to the high Cl^- concentration around the root zone. The significant decrease of E% in wheat as affected by salinity has been reported in many studies (Ashraf, Ashraf, and Ali 2010; Akbarimoghaddam *et al*. 2011; Abdelsalam 2012; Bahrani and Joo 2012). ER and MET have also been reported to be significantly affected by the increase of NaCl concentration (Rahman *et al*. 2008; Datta *et al*. 2009; Khayatnezhad *et al*. 2010; Homayoun 2011; Bahrani and Joo 2012). Datta *et al*. (2009) studied the effect of different concentrations of salinity on five cultivars of wheat (*Triticum aestivium* L.), and the results showed that E% and ER, were significantly reduced by the increase in salinity level, while MET was significantly increased. Moreover, Akbarimoghaddam *et al*. (2011) also studied the effect of different concentrations of NaCl on six cultivars of bread wheat (*Triticum aestivium* L.), and the results showed by increasing NaCl concentration, G% is decreased and delayed in all six cultivars.

The growth of wheat was also affected by salinity. It has been reported that the increase in NaCl level affects growth parameters negatively (Patel *et al*. 2010). In this experiment shoot and root length, and fresh and dry weight of shoots and roots were significantly reduced by the increase of NaCl concentration in both wheat cultivars. The reduction in shoot and root length in wheat as affected by salinity has been reported by Rahman *et al*. (2008), Ibrahim *et al*. (2008), and Sayar *et al*. (2010a). Eleiwa, Bafeel, and Ibrahim (2011) studied the effect of different levels of salinity on the growth of wheat, and the results indicated that all growth parameters such as shoot and root length, fresh and dry weight were significantly decreased

with the increase of NaCl concentration in the growth medium. Similar results were recorded by Rahman *et al*. (2008) and Akbarimoghaddam *et al*. (2011) also with wheat.

This effect of salinity on E%, ER, MET, shoot and root length, and fresh and dry weight of shoot and root can be attributed to water deficiency or ionic toxicity (Sayar *et al*. 2010b; Eleiwa, Bafeel and Ibrahim 2011). Huang and Redmann (1995), Rahman *et al*. (2008), and Bahrani and Joo (2012) reported that NaCl stress affects seed emergence either by decreasing the osmotic potential to a point which retards or prevents the uptake of water necessary for mobilisation of nutrient required for germination (osmotic effect) and or facilitating the excessive absorption of ions, which may affect certain enzymatic or hormonal activities inside the seed (ion toxic effect). Leithy, Gaballah, and Gomaa (2009) concluded that the growth performance of the plants was highly affected and decreased under salt stress. This might be due to the decrease in soil osmotic potential which inhibits the normal uptake of water and nutrients. Moreover, Eleiwa, Bafeel, and Ibrahim (2011) reported that the inhibition in seed germination might be due to a high accumulation of Na^+ ions in the seed that leads to specific ion toxicity.

It is clear from the results that the application of T1 was the best treatment that enhanced E%, ER, MET, shoot and root length, and fresh and dry weight of shoots and roots of both cultivars as compared to C. T2 was generally the second best treatment. This enhancement may be attributed to the presence of Ca^{2+} in these treatments, as Ca^{2+} plays a vital role in decreasing the osmotic potential of seeds to the point that allows the seed to uptake the necessary amount of water for germination. It has been reported that Ca^{2+} is one of the major contributors to osmotic adjustment under saline conditions (Summart *et al*. 2010). Ashraf (2004) reported that seed osmotic adjustment can be achieved by seed uptake of inorganic salts such as Ca^{2+}. Niazi *et al*. (2007) reported that increased level of Ca^{2+} applicationin the external environment reduces the osmotic effects of the growth medium. Accordingly, better

E%, ER, MET, shoot and root length, and fresh and dry weight of shoot and root could be attributed to the availability of Ca^{2+} in the growth medium. Furthermore, supplemental Ca^{2+} alleviates deleterious salt effects probably through mitigating the toxic effects of Na^{+} ions (Qadir, Qureshi, and Ahmad 2002). It has been reported that the availability of Ca^{2+} in the growth medium ameliorates the harmful effects of NaCl (Munns 2002; Zaman *et al*. 2005). Moreover, Ca^{2+} has been reported to restrict the entry of Na^{+} into the plant cells (Kader and Lindberg 2008; Um *et al*. 2012). Furthermore, Zaman *et al*. (2005) claimed that increased Ca^{2+} concentration in the saline environment inhibited Na^{+} binding to cell walls and the plasma membrane and thus decreased membrane leakage. Additionally, Al-Khateeb (2006) pointed out that the effect of Ca^{2+} addition on growth ability under saline conditions was attributed not only to the function of membranes, but also to cell elongation and cell division.

NaCl concentration in the growth medium negatively affected all growth parameters in both wheat cultivars. As compared to controls, application of T1 gave better overall results than all other treatments. T1 was the only treatment that improved all growth parameters followed by T2. Also T1 was the only treatment that had any emergence at 300 mM of NaCl. This enhancement in emergence and seedling establishment was attributed to the availability and the effect of Ca^{2+} on the water absorption and on Na^{+} uptake. However, the effect of T3, T4, T5, and T6 on the growth of both cultivars was less than T1 and T2. This probably due to the high combation of Na^{+}, K^{+} and Mg^{2+} ions on the binding sites. Moreover, T7 and T8 did not have any effect on the all growth parameters possibly because the high accumulation of Cl^{-} in the root zone. There was no clear difference between the two wheat cultivars in all investigated parameters and under all treatments.

Results suggest that the beneficial effect of compost on wheat growth and salinity tolerance can be explained by improved calcium supply in the growth medium. As mentioned by Zaman *et al*. (2005), the negative impacts of high level of NaCl on the physical and

chemical properties of soil can be alleviated by the application of different amendments that contain soluble Ca^{2+}, thus improving the growth of crops. This supports the hypothesis that Ca^{2+} was one of the factors that responsible for the growth parameters improvement under NaCl stress.

6.3. The Effect of Compost on Water Holding Capacity

One of the main roles of the soil is to store water and provide it to plants between rainfall and irrigation events. Evaporation from the soil surface, transpiration by plants and deep percolation together contribute to decrease soil moisture status between water applications. If the water is reduced toa low level, plants become water stressed. The plant available moisture storage capacity of a soil provides a buffer which determines a plant's capacity to resist drought. The addition of compost to soil may provide higher drought tolerance and more efficient water utilization. Therefore, the frequency and intensity of irrigation may be decreased and the growth and germination may be improved.

This experiment aimed to determine the effect of compost on water holding capacity.

6.3.1. Material and Methods

13 mm pots were used in this experiment. Whatman No. 2 filter papers were placed in the bottom of each potto prevent the sand falling out. Before the start of the experiment, 30% GC and 30% mix were prepared (See Chapter 4). The mass of the pot and filter paper was determined. Pots were filled with 1 kg of dry sand, 30% GC + 70% sand, and 30% mix + 70% sand separately. The pots with 1 kg of growth medium were put into a shallow tray of water and left to permit the water to get into the bottom of the pots. Irrigation was applied for all the pots to field capacity. After that pots were removed and left until water leakage had

stopped. The mass of the pots was determined again. Five replicates were used in this experiment.

Mass of the saturated soil = (mass of pot+ filter paper + saturated soil) - (mass of pot + filter paper)

Mass of water contained in the saturated soil (%) = (mass of the saturated soil - mass of dry soil /mass of dry soil) × 100.

6.3.2. Results

One way ANOVA showed that both composts had a significant effect on the water holding capacity compared to sand. The mean water holding capacity of 30% GC was 46.2% with a medium of 300 g GC and 700 g sand, while it was 43.6% with a medium of 300 g mix and 700 g sand. However, mean water holding capacity of sand was only 21.8%. There was no significant difference between the two composts, but both composts significantly improved the water holding capacity as compared to sand (Table 6.23).

Table 6.23. The effect of compost on the water holding capacity (%) (range in brakets, n = 5).

Growth medium	WHC (%)
30% GC	46[a] (45-49)
30% mix	43[a] (42-46)
Sand	21[b] (18-23)

6.3.3. Discussion

Water is held in the spaces between soil particles and in thin films surrounding soil particles. Organic matter can enhance aggregation of soil particles, thus increasing the surface area of soil particles which leads to an increase in the soil water holding area, and the reby improves the water holding capacity. Compared to sand, 30% GC and 30% mix resulted in significantly enhanced water holding capacity. Water holding capacity was reported to be higher in soils

with a large amount of organic matter (Parthasarathi, Balamurugan, and Ranganathan 2008). Compost is a source of organic matter (Sarwar *et al.* 2007). Lawson, Hayatsu, and Nioh (2004) reported that the application of compost to the soil improved soil moisture status. Furthermore, Tester (1990) and Ferreras *et al*. (2006) pointed out that the addition of compost to the soil significantly increased the water holding capacity. Qadir, Ghafoor, and Murtaza (2001), and Walker and Bernal (2008) reported that in saline or sodic soils, the application of organic matter can increase water holding capacity and aggregate stability.

It can be concluded that the application of compost leads to an improvement in water holding capacity. Both compost treatments succeeded in significantly improving the water holding capacity of soil. Therefore, water holding capacity can be considered one of the key factors in improving the growth of both wheat cultivars under saline environments.

6.4. The Effect of Priming on Seed Water Uptake

Water uptake is a fundamental prerequisite in the initiation of biochemical changes that lead to the seeds completing germination (Manz *et al.* 2005; Siddiqui and Khan 2010). The water imbibed by the seed contributes in activating enzymes that assist mobilization and translocation of seed reserves. Hence, seed water uptake is a necessary stage for the metabolism of stored starch and protein in the seed (Kikuchi *et al*. 2006; Abebe and Modi 2009), which guarantees the supply of nutrients to the embryo to generate energy for the initiation of active germination and seedling growth **(**Abebe and Modi 2009**).**

Water uptake can be decreased in a saline environment due to the increase in osmotic pressure (Dixit and Chen 2010). Moreover, seed water deficiency is probably the main physiological mechanisms for a reduction in growth. Thus, this experiment aimed to determine the effect of pre-sowing seed treatment with $CaCl_2$ on the availability of water under different NaCl concentrations.

6.4.1. Material and Methods

Seeds of the two wheat cultivars were soaked in 100 ml of 50 mM $CaCl_2$ as described in Chapter 3. Containers were kept in a growth incubator at 25 °C for 17 h for priming. After that seeds were washed a few times with distilled water and left to surface dry. Two grams of primed seeds of each cultivar and unprimed seeds were soaked in 10 ml of distilled water and were left for 24 h. A reading of mass was taken after 24 h. Seeds were surface dried and weighed using an electronic balance and replaced again.

1 priming agents + non-priming = 2 × 2 wheat cultivars = 4 treatment × 3 = 12 replicates

Water uptake was calculated using the following equation (Akbarimoghaddam *et al*. 2011).

$$\text{Water uptake \%} = \frac{W2-W1}{W1} \times 100$$

Where:

W_1 = Initial weight of seed

W_2 = weight of seeds after absorbing water at end of each time period.

Data were statistically analysed using three way ANOVA. Tukey's test at $p \leq 0.05$ was used. The water uptake percentage was arcsine transformed before analysis.

6.4.2. Results

Three way ANOVA showed that the effect all factors and their combinations on seed water uptake was significant ($p < 0.05$) (Table 6.24).

Table 6.24. The significance of interactions between treatments using ANOVA for water uptake.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	<0.01

An inverse relationship was observed between water uptake by seeds and increase of NaCl concentration up to 300 mM. The increase of NaCl concentration affected seed water uptake significantly whether seeds were primed or not.

Table 6.25. Effect of different salinity levels on water uptake (%) of primed seeds with $CaCl_2$ and unprimed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) after 24 h of soaking (mean values, range in brackets, n = 5).

Cultivar	Treat	NaCl (mM)			
		0	100	200	300
Slambo	P	61^{b}(59-62)	52^{d}(50-53)	47^{e}(46-48)	32^{h}(30-35)
	UP	47^{e}(45-47)	42^{f}(42-43)	37^{g}(35-39)	27^{i}(26-27)
S-24	P	67^{a}(64-68)	59^{bc}(57-60)	57^{c}(55-58)	45^{ef}(44-47)
	UP	57^{c}(56-58)	47^{e}(43-49)	44^{ef}(43-44)	36^{g}(32-38)

The significant effect of priming on seed water uptake was identified at all NaCl concentrations in both wheat cultivars (Table 6.25). Moreover, the effect of cultivar on seed water uptake was shown at all NaCl concentrations with primed and unprimed seeds. Considerable variation between cultivars in response to salinity was observed for water uptake such that water uptake of cv. S-24 was significantly higher than water uptake by cv. Slambo at all NaCl concentrations.

Table 6.26. Summary of experimental investigation for water uptake (%)

Cultivar	Priming	NaCl Concentration			
		0	100	200	300
S-24	P	✓	✓	✓	✓
Slambo	P	✓	✓	✓	✓

✓ = significant effect compared to unprimed seeds.

6.4.3. Discussion

In this study, seed water uptake decreased significantly with increasing NaCl concentrations in the two investigated cultivars. Water uptake ranged from 47.5 – 67.29% in unstressed

conditions to 27.18 – 45.96% at 300 mM. This decline in the seed water uptake is probably due to the decrease of osmotic potential in the growing solution. Mohammadi (2009), Akbarimoghaddam *et al*. (2011), and Ghogdi, Izadi, and Borzouei (2012) reported that the increase of NaCl concentration in the growing medium leads to a decrease in the external osmotic potential which prevents water uptake by the seed. Moreover, Lakhdar *et al*. (2008) reported that one growth suppression mechanisms is the disturbance of plant water uptake as a result of the decrease of osmotic potential in the growth medium around the root zone. Furthermore, Sayar *et al*. (2010a) mentioned that water uptake by a plant or seed can be limited by a decrease of the osmotic potential of soil solution due to the accumulation of soluble salts in the growth medium.

This result is in agreement with Pesserakli, Tucker, and Nakabayaski (1991); Saboora *et al*. (2006); Maghsoudi and Maghsoudi (2008); Rahman *et al*. (2008); Akbarimoghaddam *et al*. (2011) and Murungu (2011) with wheat and Mohammadi (2009) with canola.

In both wheat cultivars, seeds subjected to priming showed significantly higher water uptake than unprimed seeds at all NaCl concentrations. This result is in line with the findings of Jamil and Rha (2007). This increase of seed water uptake in primed seeds is probably due to the effect of priming on osmotic potential. Pre-sowing seed treatments decreased the osmotic potential inside the seeds as a result of the absorbtion of priming solution during the soaking period. In order to absorb water, plants must decrease their cell water potential (Ashraf 2004). This process is known as osmotic adjustment and can be achieved by accumulation of organic or inorganic salts such as Ca^{2+}, Na^{+}, K^{+} in the plant tissue (Ashraf 2004). Thus, better water uptake of primed seeds could be attributed to increased accumulation of Ca^{2+} due to soaking in $CaCl_2$.

Hartman *et al*. (2002) and Murungu (2011) reported that seeds spend significant amounts of time absorbing water from the growing medium. Thus, by decreasing the water absorbtion

time to a minimum, because of seed priming, seed germination rate and seedling emergence can be enhanced. Khayatnezhad *et al*. (2010) mentioned that seed germination is strongly related to the amount of absorbed water. In previous experiments (Chapter 3), the results showed that priming enhanced the germination of both cultivars under saline conditions. Therefore, the enhanced germination due to priming might be explained bymore rapid water uptake in primed seeds than in unprimed seeds of both cultivars as suggested by Jamil and Rha (2007). Furthermore, water uptake by cv. S-24 was significantly higher than water uptake by cv. Slambo in primed and unprimed seeds at all NaCl concentrations, and this may explain why the performance of cv. S-24 is sometimes better than cv. Slambo under NaCl stressed conditions.

6.5. The Effect of Priming on Seed Ion Leachate

As dry seeds are soaked in water, they start to leak electrolytes such as ions and sugars (Fessel *et al*. 2006). Givelberg, Horowitz, and Poljakoff-Mayber (1984) reported that seed leakage can be due to damageto membrane integrity, and this damage can be higher undersalt-stressed conditions than under normal conditions (Ghoulam, Foursy, and Fares 2002). Moreover, Fessel *et al*. (2006) pointed out that the membrane repair of low vigour seeds is either insufficient or entirely inhibited, leading to a high level of electrolyte leakage. Hence, the lower the membrane integrity the greater the ion leakage. Therefore, to investigate the effect of the selected priming treatment on ion leakage, an experiment was designed to determine the ion leakage by measuring the electrical conductivity during imbibition. This provides an important measure of the ability of Ca^{2+} to enhance membrane integrity.

6.5.1. Material and Methods

The selected priming treatment ($CaCl_2$) was prepared prior to the experiment and seeds were primed as mentioned previously (Chapter 3). After this seeds were washed with distilled water to remove any trace of priming treatment and left to surface dry. Two grams of primed seeds from each cultivar and non-primed seeds (control) were each put in plastic beakers containing 50 ml of distilled water (Farooq *et al.* 2004; Afzal *et al.* 2007a). Five replicates of each treatment were used. The beakers were put in a growth incubator at 25°C.

2 priming treatments (including control) × 2 wheat cultivars × 5replicates = 20 beakers

Before the start of the experiment, the electrical conductivity meter was calibrated by using potassium chloride solution. The electrical conductivity of seed leachates was measured after 0.5, 1.0, 1.5, 2.0, 6.0, 12, and 24 hours of soaking (Afzal *et al.* 2007a; Afzal *et al.* 2007b; Basra *et al.* 2005) using a digital conductivity meter Model (PTI-8, UK) and expressed as µS $cm^{-1}g^{-1}$. The conductivity of seeds per gram was calculated usingthe following equation

EC per gram of seeds = (Conductivity (µS cm^{-1})) / Weight (g) of seed lot) = µS cm^{-1} g^{-1}

The data from each time interval were statistically analysed using two way ANOVA for each time point separately. Tukey's test at $p \leq 0.05$ was used to determine significant between treatment differences.

6.5.2. Results

Two way ANOVA showed that the effect of cultivar, priming and the interaction between cultivar and priming on the seed ion leakage was significant ($p < 0.05$) (Table 6.27).

Table 6.27. The significance of interactions between treatments using ANOVA for seed ion leachates.

Treatment Combination	Time of Soaking (h)						
	0.5	1	1.5	2	6	12	24
Cultivar	S	S	S	S	S	S	S
Priming	S	S	S	S	S	S	S
Cultivar*Priming	S	NS	NS	NS	S	S	S

S = Significant effect
NS = Not significant effect

Pre-sowing seed treatment with 50 mM of $CaCl_2$ positively affected the electrical conductivity of seed leachates (Figure 6.1). Pre-sowing seed treatment decreased the electrical conductivity of seed leachates significantly ($p < 0.05$) at all soaking periods in both wheat cultivars as compared with unprimed seeds. Furthermore, the performance of cv. S-24 was better than cv. Slambo for primed seeds as cv. S-24 had a significantly lower ion leakage than cv. Slambo at 1.5, 2, 6, 12 and 24 h of soaking.

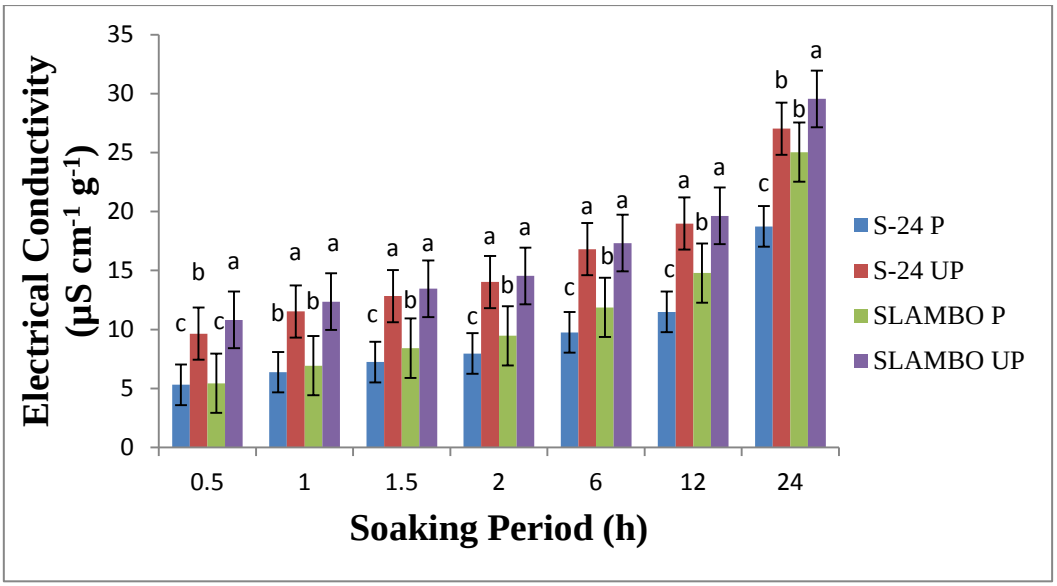

Figure 6.1. Effect of priming with $CaCl_2$ on the electrical conductivity of seed leachates in wheat (*Triticum aestivum* L. cv Slambo and cv. S-24) (n = 5).

Table 6.28. Summary of experimental investigation for the electrical conductivity of seed leachates

Cultivar	Period of Soaking						
	0.5	1	1.5	2	6	12	24
S-24	✓	✓	✓	✓	✓	✓	✓
Slambo	✓	✓	✓	✓	✓	✓	✓

✓ = significant effect compared to unprimed seeds.

6.5.3. Discussion

The electrical conductivity test shows the level of leached ions from seeds, which indicates the level of seed vigour, and consequently its ability to grow in harsh environments such as saline soil.

The determination of electrical conductivity of leachates gives a measurement of the extent of electrolyte leakage from seed tissues (International Seed Testing Association 2003). Sadeghi *et al*. (2011) reported that the electrical conductivity test is applied to quantify the leakage of electrolytes from the seed coat. Furthermore, Afzal *et al*. (2007b) claimed that seed leachate electrical conductivity is considered as an effective indicator of seed germination.

The extent of electrolyte leakage is affected by the capacity of seed cellular membranes to repair any damage. The faster membranes reorganize, the lower the electrolyte leakage and the greater the seed vigour (International Seed Testing Association 2003). Therefore, the ability of less leakage seeds to establish in a stressed environment will be greater than those of higher leakage seeds (Hampton 1995).

The result of this investigation showed that electrical conductivity of seed leachates was higher in unprimed seeds than in primed seeds at all periods of time in both wheat cultivars. This increase is probably due to the loss of ability to reorganize cellular membranes quickly

and as suggested by Tajbakhsh (2000); Afzal *et al*. (2004; 2005; 2006b and 2007b). However, the results of this study showed that a presowing seed treatment with 50 mM of $CaCl_2$ reduced the seed leakage significantly as compared with non-primed seeds in both wheat cultivars at almost all periods of time. Afzal *et al*. (2007b) studied the effect of different $CaCl_2$ and NaCl concentrations on the seed leachate of wheat and the results showed that priming with 10, 25 and 50 mM of $CaCl_2$ decreased seed leakage compared with NaCl priming and controls. The reduction in the electrical conductivity of seed leachates of solute in primed seeds might be due to better membrane repair during hydration which resulted in lower seed leachate rate (Basra *et al*. 2003; Afzal *et al*. 2004; Afzal *et al*. 2007a; Afzal *et al*. 2007b; Khan *et al*. 2010). Furthermore, the beneficial effect of $CaCl_2$ priming on reducing seed leachate could be due to increased Ca^{2+} seed content. It has been reported that Ca^{2+} has a positive effect on membranes (Afzal *et al*. 2008). Iqbal (2005) reported that Ca^{2+} protects membranes from the negative effects of sodium by maintaining membrane integrity and reducing leakage of cytoplasmic potassium. In addition, this study also showed that the electrical leakage of cv. S-24 was significantly lower than cv. Slambo in primed seeds at most time points, suggests that cultivars may respond differently to priming treatment. It can be concluded that seed priming with $CaCl_2$ has a positive effect on the seed ion leakage due to the effect of Ca^{2+} in improving membrane integrity, which decreases the leakage of important ions. This is of importance particularly for seeds grown under salt stressed conditions as it is expected that their performance will be higher than unprimed seeds.

6.6. The Effect of Priming on Seed Ion Uptake

Ion uptake is an essential factor not only for normal growth but also for growth under stressed conditions such as salinity (Parida and Das 2004). It has been reported that salinity has harmful effects on seed germination not only by osmotic effect through decrease in water

absorption but also by ionic effect through the increase of Na^+ and Cl^- level causing toxicity and an imbalance in nutrient uptake (Othman *et al*. 2006). Ullah, Gerzabek and Soja (1994) reported that salinity affects the accumulation and the uptake of ions of a number of species such as wheat, barley, rice, cotton, sugar beet and beans. Moreover, Karmoker, Farhana, and Rashid (2008) mentioned that an imbalance of ion uptake can occur due to the effects of salt stress. Therefore, this experiment aimed to determine the effect of priming treatment on the ability of seeds to absorb (Na^+, Ca^{2+}, Mg^{2+} and K^+).

6.6.1. Material and Methods

Before the start of the experiment, seeds of both cultivars were primed as mentioned previously (Chapter 3). After this seeds were removed and washed with distilled water for a few minutes to eliminate the trace of priming treatment. Seeds were then left to surface dry. Twenty Primed and unprimed seeds from each cultivar were soaked in different NaCl concentrations (0, 100, 200 and 300 mM) separately for 24 h. After that, seeds were dried at 80 °C for 48 h (Afzal *et al.* 2008). Seed ion uptake was determined using Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP- AES). Digestion process was done with microwave oven method as described earlier.

2 priming treatments (including control) × 2 wheat cultivars × 4 NaCl concentrations × 5 replicates = 80 beakers

6.6.2. Results

The results show that there was a negative correlation between the increase in NaCl concentration and seed ion uptake in both wheat cultivars. Seed ion uptake decreased significantly ($p < 0.05$) as salt concentration increased.

Seed Na^+ Content

Three way ANOVA indicated that all the factors and combinations had a significant effect ($p < 0.05$) on the seed Na^+ content (Table 6.29).

Table 6.29. The significance of interactions between treatments using ANOVA for seed ion content of Na^+.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	<0.01

The effect of NaCl stress on seed Na^+ concentration is shown in Table 6.30. The results showed that seed content of Na^+ increased significantly in response to increasing NaCl level in both wheat cultivars. This increase was significant at all salinity levels whether seeds were primed or not.

Table 6.30. Effect of different salinity levels on seed Na^+ concentration (g kg^{-1}) of primed seeds with $CaCl_2$ and unprimed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, n = 5).

NaCl (mM)	Na^+ (gkg^{-1})			
	S-24		Slambo	
	P	UP	P	UP
0	0.16^{f}(0.06)	0.21^{f}(0.05)	0.15^{f}(0.05)	0.20^{f}(0.00)
100	0.68^{e}(0.03)	0.86^{cde}(0.02)	0.74^{de}(0.03)	0.99^{c}(0.01)
200	0.86^{cd}(0.04)	1.36^{b}(0.01)	1.31^{b}(0.06)	1.46^{b}(0.02)
300	1.34^{b}(0.06)	1.67^{a}(0.05)	1.66^{a}(0.01)	1.73^{a}(0.05)

With no addition of NaCl, the difference between primed and unprimed seeds was not significant in either wheat cultivar. At 100 mM of NaCl, the difference was significant in cv. Slambo seeds. Conversely, at 200 and 300 mM the difference was significant in cv. S-24 but

not cv. Slambo. However, the Na^+ uptake of cv. S-24 was significantly lower than cv. Slambo with primed seeds at 200 and 300 mM of NaCl.

Seed Ca^{2+} Content

Three way ANOVA also indicated that all the factors and combinations had a significant effect ($p < 0.05$) on the seed Ca^{2+} content (Table 6.31).

Table 6.31. The significance of interactions between treatments using ANOVA for seed ion content of Ca^{2+}.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	S	<0.01
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	<0.01

Table 6.32 represents the influence of NaCl levels on the seed uptake of Ca^{2+}. The data revealed that Ca^{2+} content of cv. S-24 primed seeds was significantly higher than unprimed seeds under all NaCl concentrations, while in cv. Slambo, Ca^{2+} content of primed seeds was significantly greater than unprimed seeds at 0 and 100 mM only.

Table 6.32. Effect of different salinity levels on seed Ca^{2+} concentration (g kg^{-1}) of primed seeds with $CaCl_2$ and unprimed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, n = 5).

NaCl (mM)	Ca^{2+} (g kg^{-1})			
	S-24		Slambo	
	P	UP	P	UP
0	0.56^{a}(0.01)	0.42^{b}(0.01)	0.53^{a}(0.07)	0.35^{c}(0.01)
100	0.42^{b}(0.01)	0.35^{c}(0.00)	0.35^{c}(0.02)	0.27^{ef}(0.00)
200	0.43^{b}(0.01)	0.34^{cd}(0.00)	0.30^{de}(0.01)	0.25^{ef}(0.01)
300	0.40^{b}(0.00)	0.29^{e}(0.00)	0.24^{f}(0.00)	0.23^{f}(0.01)

The effect of cultivar on Ca^{2+} was very pronounced. Under all NaCl concentrations whether seeds were primed or not, Ca^{2+} content of cv. S-24 was significantly higher than in cv. Slambo except with primed seeds at 0 mM.

Seed K^+ Content

Three way ANOVA indicated that all the factors and combinations had a significant effect ($p < 0.05$) on the seed K^+ content except the interaction between cultivar and NaCl concentration (Table 6.33).

Table 6.33. The significance of interactions between treatments using ANOVA for seed ion content of K^+.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	S	<0.01
Cultivar*NaCl Concentration	NS	0.08
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	<0.01

The effect of salinity on K^+ seed content is shown in Table 6.34. The results showed that in unstressed conditions there was no significant difference between primed and unprimed seeds in either wheat cultivars. However, at concentrations of 100, 200 and 300 mM NaCl, the K^+ content of cv. S-24 primed seeds was significantly greater than in unprimed seeds, while no significant difference was recorded between primed and unprimed seeds of cv. Slambo at these NaCl concentrations. In addition, the effect of cultivar was apparent in primed seeds at 100, 200 and 300 mM, where cv. S-24 had a significantly higher K^+ content than cv. Slambo.

Table 6.34. Effect of different salinity levels on seed K^+ concentration (g kg^{-1}) of primed seeds with $CaCl_2$ and unprimed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, n = 5).

NaCl (mM)	K^+ (g kg^{-1})			
	S-24		Slambo	
	P	UP	P	UP
0	3.68^{a}(0.10)	3.45^{abc}(0.03)	3.28^{bcd}(0.09)	2.97^{def}(0.06)
100	3.52^{ab}(0.05)	2.79^{efg}(0.02)	2.82^{efg}(0.06)	2.50^{ghi}(0.07)
200	3.34^{abc}(0.06)	2.55^{ghi}(0.05)	2.65^{fgh}(0.08)	2.38^{hij}(0.06)
300	3.12^{cde}(0.03)	2.23^{ijk}(0.08)	2.12^{jk}(0.07)	1.91^{k}(0.08)

Seed Mg^{2+} content

Three way ANOVA indicated that all treatments had a significant effect ($p < 0.05$) on the Mg^{2+} seed content except the interaction between cultivar and priming, and the overall interaction (Table 6.35).

Table 6.35. The significance of interactions between treatments using ANOVA for seed ion content of Mg^{2+}.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.94
Cultivar*NaCl Concentration	S	0.04
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	NS	0.48

In general, the effect of salinity on seed Mg^{2+} concentration was less evident than for Na^+, K^+ and Ca^{2+}. The data revealed that in cv. S-24, a significant difference between priming and unprimed seeds occurred at 300 mM, whereas in cv. Slambo, this was apparent only at 100 mM (Table 6.36). Furthermore, there was no difference between cultivars at any level of NaCl.

Table 6.36. Effect of different salinity levels on seed Mg^{2+} concentration (g kg^{-1}) of primed seeds with $CaCl_2$ and unprimed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, n = 5).

NaCl (mM)	Mg^{2+} (g kg^{-1})			
	S-24		Slambo	
	P	UP	P	UP
0	1.19^{abc}(0.01)	1.18^{abc}(0.01)	1.39^{a}(0.06)	1.31^{a}(0.05)
100	1.16^{abc}(0.01)	1.00^{cde}(0.01)	1.27^{ab}(0.03)	1.03^{cde}(0.06)
200	1.07^{bc}(0.03)	0.99^{cde}(0.02)	1.06^{bc}(0.04)	1.05^{bcd}(0.07)
300	1.06^{bc}(0.06)	0.81^{e}(0.02)	1.02^{cde}(0.03)	0.82^{de}(0.04)

Seed K^+: Na^+ Ratio

Three way ANOVA indicated that all factors had a significant effect ($p < 0.05$) on the K^+: Na^+ ratio (Table 6.37). However, the interaction between cultivar and priming, and cultivar and NaCl concentrations was not significant ($p > 0.05$).

Table 6.37. The significance of interactions between treatments using ANOVA for seed ion content of K^+: Na^+ ratio.

Treatment Combination	Significant or not	p
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.27
Cultivar*NaCl Concentration	NS	0.40
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	<0.01

Table 6.38 represents the influence of NaCl levels on the K^+: Na^+ ratio. This ratio decreased as NaCl concentration increased in both cultivars whether seeds were primed or not. This decrease was from 14.2 - 22.1 in unstressed conditions to 1.1 - 2.3 at 300 mM.

At all salt concentrations, the K^+: Na^+ ratio in cv. S-24 primed seeds was significantly higher than in unprimed seeds except at 300 mM. For cv. Slambo, the K^+: Na^+ ratio of primed seeds was significantly greater than unprimed seeds only at 0 and 100 mM but not at 200 and 300 mM.

Table 6.38. Effect of different salinity levels on seed K^+: Na^+ ratio of primed seeds with $CaCl_2$ and unprimed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, n = 5).

NaCl (mM)	K^+: Na^+			
	S-24		Slambo	
	P	UP	P	UP
0	22.10^{a}(0.79)	16.47^{b}(0.46)	21.50^{a}(0.59)	14.21^{c}(0.52)
100	5.16^{d}(0.27)	3.25^{ef}(0.09)	3.84^{efg}(0.23)	2.53^{d}(0.07)
200	3.91^{de}(0.23)	1.87^{fg}(0.04)	2.02^{fg}(0.07)	1.63^{fg}(0.03)
300	2.33^{efg}(0.09)	1.33^{g}(0.03)	1.27^{g}(0.04)	1.10^{g}(0.06)

The effect of cultivar on the K^+: Na^+ ratio was apparent in some cases. For cv. S-24, primed seeds at 100 and 200 mM, and unprimed seeds at 0 and 100 mM had a significantly greater K^+: Na^+ ratio than equivalent seeds of cv. Slambo.

Seed Ca^{2+}: Na^+ Ratio

Three way ANOVA showed that all factors and their combinations had a significant effect ($p < 0.05$) on the the Ca^{2+}: Na^+ ratio, except the interaction between cultivar and priming, and cultivar and NaCl concentration (Table 6.39).

Table 6.39. The significance of interactions between treatments using ANOVA for Ca^{2+}: Na^+ratio.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	S	<0.01
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.72
Cultivar*NaCl Concentration	NS	0.74
Priming* NaCl Concentration	S	<0.01
Cultivar*Priming* NaCl Concentration	S	<0.01

Table 6.40 shows the influence of NaCl levels on the Ca^{2+}: Na^+ ratio in seeds. The data showed that Ca^{2+}: Na^+ ratio in primed and unprimed seeds decreased as NaCl concentration increased in both wheat cultivars. This reduction was from 1.7 - 3.4 at 0 mM to 0.09 - 0.3 at

300 mM. Moreover the only effect of priming on the Ca^{2+}: Na^{+} ratio was recorded at 0 mM where the ratio was higher in primed seeds than in unprimed seeds of both cultivars. Furthermore, the difference between cultivars was not significant at all NaCl concentrations.

Table 6.40. Effect of different salinity levels on seed Ca^{2+}: Na^{+} ratio of primed seeds with $CaCl_2$ and unprimed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, n = 5).

NaCl (mM)	Ca^{2+}: Na^{+}			
	S-24		Slambo	
	P	UP	P	UP
0	3.38^{a}(0.2)	2.01^{b}(0.06)	3.49^{a}(0.09)	1.71^{b}(0.06)
100	0.62^{c}(0.01)	0.41^{cdef}(0.01)	0.47^{cde}(0.01)	0.27^{def}(0.00)
200	0.50^{cd}(0.01)	0.25^{def}(0.00)	0.23^{def}(0.01)	0.17^{ef}(0.01)
300	0.30^{def}(0.01)	0.17^{ef}(0.01)	0.17^{f}(0.00)	0.09^{f}(0.01)

Table 6.41. Summary of experimental investigation for seed ioncontent.

Cultivar	Priming	NaCl	Seed Ion Content					
			Na^{+}	Ca^{2+}	K^{+}	Mg^{2+}	Ca^{2+}:Na^{+}	K^{+}:Na^{+}
S-24	P	0		✓			✓	✓
		100		✓	✓			✓
		200	✓	✓	✓			✓
		300	✓	✓	✓	✓		
Slambo	P	0		✓			✓	✓
		100	✓	✓		✓		✓
		200						
		300						

✓ = significant positive effect compared to unprimed seeds

6.6.3. Discussion

Preserving nutrition with Ca^{2+} and K^{+} is an essential feature contributing to salt tolerance in plants (Karmoker, Farhana ,and Rashid 2008). The results of this experiment showed that seed ion content was reduced with the increase in NaCl concentration in both cultivars.

Othman *et al.* (2006) studied the effect of salinity conditions on the ion uptake of barley, and the results showed that ion uptake was strongly affected by the increase in salinity. Parida and Das (2004), and Farhoudi and Sharifzadeh (2006) pointed out that the increase of salinity level causes an increase in Na^+ and Cl^- concentrations and reduces the concentrations of Ca^{2+}, K^+ and Mg^{2+} in a number of plants. A similar finding was reported by Ibrahim *et al*. (2007) with wheat. Pre-sowing seed treatments have been found to enhance the ion uptake of seeds. Afzal *et al*. (2008) reported that seed priming improved the ion content of wheat in a saline environment through which salt tolerance is improved.

Regardless of treatment, the results of this study indicated that Na^+ concentration increased markedly in response to increasing salt stress level in both wheat cultivars. Tammam, Alhamd, and Hemeda (2008) studied the effect of salinity on wheat and the result indicated that the concentration of Na^+ increased with the increase in salinity level. This result corroborates the finding of Hussain *et al*. (2009), Carpici *et al*. (2010), Dkhil and Denden (2010), Qin *et al*. (2010), and Taffouo *et al*. (2010).

It has been reported that Na^+ accumulation in the plant under saline conditions is at the expense of Ca^{2+} and K^+ (Patel *et al*. 2010). According to Taffouo *et al*. (2010) in most saline soils, NaCl is the prevalent salt that increases the concentration of Na^+ and Cl^- and consequently affects the uptake of other mineral elements. A variety of osmotic and metabolic problems for plants can result from an increase in the Na^+ level in tissues (Bonilla, Hamdaoui, and Bolanos 2004). The toxic effect of Na^+ is mainly due to the competition between Na^+ with other nutrients such as K^+ for binding sites (Yildirim, Karlidag, and Turan 2009; Qin *et al*. 2010). Othman *et al*. (2006) suggested that the increase of Na^+ accumulation in the seed affects seed germination, namely by influencing the water relations of the seed or through displacement of Ca^{2+} by Na^+ from critical cell wall binding sites which could obstruct cell wall synthesis and therefore reduce the growth of plants.

Many studies indicate that seed priming reduces the concentration of Na^+ under salt stress. The findings of this study agree with those of Afzal *et al*. (2008) who found that priming wheat seeds with 50 mM of $CaCl_2$ decreased the Na^+ content significantly under NaCl conditions when compared to unprimed seeds.

Calcium is a divalent cation that is essential in regulating the uptake of nutrients across cell membranes. Calcium plays an important role in plant cell division and elongation, structure and permeability of cell membranes, carbohydrate translocation and enzymatic activities (Taiz and Zeiger 2006; Gobinathan, Murali and Panneerselvam 2009). Moreover, Shaikh *et al*. (2007) mentioned that the increase of Ca^{2+} concentration mitigates the negative influence of salt stress by decrease or inhibition of the absorption of Na^+ ions. Salinity has a negative effect on seed content of Ca^{2+} ions. Rehman *et al*. (2000) reported that a deficiency of Ca^{2+} caused by salt stress has been reported in various plant species such as wheat (Afzal *et al*. 2008) and rice (Alamgir, Musa, and Ali 2007). Patel *et al*. (2010) investigated the effect of salinity on the ion uptake of three cowpea cultivars, and the results indicated that salinity decreased the concentration of Ca^{2+} significantly in all cultivars. This decrease of Ca^{2+} causes loss of membrane integrity in saline conditions as a result of Ca^{2+} displacement due to high Na^+ concentration (Naeem and Muhammad 2006). The results of this study also indicated that the decrease in Ca^{2+} concentration and increase in Na^+ concentration led to a reduction in the Ca^{2+}: Na^+ ratio. Similar results were obtained by a number of other researchers (El-Juhany, Aref, and Ahmed 2008; Karmoker, Farhana, and Rashid 2008; Khorshidi, Yarnia, and Hassanpanah 2009).

In keeping with the results of this study, it has been reported that the beneficial effect of priming with $CaCl_2$ on the seed Ca^{2+}content was observed for a number of species. Afzal *et al*. (2008) found that primed seeds of two wheat cultivars in 50 mM solution of $CaCl_2$ increased the ion content of Ca^{2+}. Farooq, Barsa, and Khan (2007) and Farooq *et al* (2010b)

reported that seed priming with $CaCl_2$ increased the seed Ca^{+2} ion content of rice (*Oryza sativa*), which is crucial for seed metabolism. A similar finding was reported by Farooq *et al*. (2006).

It has been claimed that there is a negative correlation between ion leakage and seed vigour (International Seed Testing Association 2003), and it is expected that seedsthat leak less are able to perform better under adverse environmental conditions. The result of this study showed that the Ca^{2+} seed content of cv. S-24 was significantly higher than cv. Slambo, and after soaking in NaCl, the cv. S-24 seeds lost less Ca^{2+} than cv. Slambo at all NaCl levels. This suggests that cv. S-24 seeds had the ability to bind Ca^{2+} better than cv. Slambo. The results also showed that the performance of cv. S-24 was slightly better than cv. Slambo in termsof germination percentage and emergence percentage under saline conditions. This better performance is probably due to the ability of seeds to bind Ca^{2+} ions. With all of these previously mentioned studies, the increased Ca^{2+} content due to priming was associated with significantly enhanced salt tolerance. Thus, the increase of germination percentage and emergence percentage of cv. S-24 and cv. Slambo due to priming could be attributed to the beneficial effect of priming which enhanced the seed Ca^{2+} content.

Potassium is an important macronutrient (Rehman *et al*. 2000). Zekri and Obreza (2009) reported that the presence of K^+ in the plant activates enzymatic activities, and regulates CO_2 supply and decreases the water loss from the leaves due to its control on opening and closing stomata. Salinity has been reported to reduce K^+ concentration (Othman *et al*. 2006). This reduction in K^+ concentration could reduce growth by decreasing the capacity for osmotic adjustment and turgor maintenance or by negatively influencing metabolic functions (Patel *et al*. 2010). It has been reported that K^+ and Ca^{2+} are the most important cations for osmotic adjustment under saline environments (Summart *et al*. 2010). Royo and Abio (2003) studied the effect of salinity on ion absorption of seventeen wheat cultivars, and the results showed

that there is a negative correlation between salinity and K^+ concentration, as salt level was increased, K^+ concentration was reduced. Afzal *et al*. (2006a) reported that K^+ concentration of two wheat cultivars was decreased with the increase of salt stress level. Several other studies produced similar findings including Hussain *et al*. (2009), Patel *et al*. (2010), Dkhil and Denden (2010) and Carpici *et al*. (2010).

Patel *et al*. (2010) reported that the decrease in K^+ content can affect the growth by decreasing the osmotic adjustment capacity and turgor maintenance. Many studies indicated that the decrease in K^+ concentration leads to a reduction in the K^+: Na^+ ratio. This decrease in the K^+: Na^+ ratio is also reported by Tammam, Alhamd, and Hemeda (2008) and Ragab, Hellal, and El-Hady (2008) with wheat. Shirazi *et al*. (2005) and Dkhil and Denden (2010) suggested that the decrease of K^+ content, the increase of Na^+ content and reduced K^+: Na^+ ratios in plants could be attributed to the effect of competition between Na^+ and K^+ ions at the absorptive sites of the plant.

In this study, as compared to unprimed seeds, enhanced K^+ content was recorded in cv. S-24 primed seeds at 100, 200 and 300 mM while in cv. Slambo, there was no enhancement at all NaCl concentrations. This may explain why the germination was better in cv. S-24 than in cv. Slambo under saline conditions. Afzal *et al*. (2008) found that priming seeds with 50 mM of $CaCl_2$ solution increased the seed content of K^+ in two wheat cultivars. This increase is probably due to the effect of Ca^{2+} on the K^+ concentration. Royo and Abio (2003) indicated that the negative effect of salt stress in plants with decreased K^+ absorption can be reduced with increasing Ca^{2+} level. It has been reported that Ca^{2+} maintains membrane integrity and K^+ transport and K^+: Na^+ selectivity in salinity affected plants (Iqbal 2005; Gobinathan, Murali and Panneerselvam 2009). Zaman *et al*. (2005) studied the response of wheat to sodium and calcium ions in a saline environment. The results showed that maintaining an optimum K^+: Na^+ ratio relies on Ca^{2+} concentration which can regulate and sustain K^+ level

in plants. It has been reported that the ability of plants to accumulate a high K^+ in the cytoplasm relative to that of Na^+ may be a contributing factor in determining their salt tolerance (Rehman *et al*. 2000; Munns and Tester 2008; and Patel *et al*. 2010).

Magnesium plays an important role as an enzyme activator and is considered a key element of chlorophyll molecules and in seed germination (Kelly 2004; El-Metwally *et al*. 2010). Many reports indicated that salinity affects seed content of Mg^{2+} ions. In this study, Mg^{2+} concentration was decreased as salt level increased. Tammam, Alhamd, and Hemeda (2008) studied the effect of different levels of salinity on wheat, and the results showed that Mg^{2+} decreased with the increase of salt stress. This result is also in agreement with Heidari and Jamshid (2010). The effect of presowing seed treatment with $CaCl_2$ on Mg^{2+} was not clear, the only increase in Mg^{2+} concentration in cv. S-24 was recorded at 300 mM as compared to unprimed seeds while in cv. Slambo, it was recorded only at 100 mM. This may be due to the effect of the increase of Ca^{2+} concentration as both are divalent cations.

It can be concluded that salinity negatively affected the seed ion content. Ca^{2+}, $K^+$and Mg^{2+} decreased as NaCl concentration was increased, while Na^+ content increased with the increase in salinity. Priming enhanced the seed ion content in both cultivars, but the performance of cv. S-24 was better than cv. Slambo especially under high levels of salinity.

6.7. The Effect of Priming on the Seed Recovery

Seed germination is an important stage in the life cycle of plants, especially those growing in saline environments. The three steps of germination processes are imbibition, metabolism and radical growth. Germinating seeds require enough imbibition in order to reactivate the metabolic processes. However, at a high salinity, germination is inhibited (Delachiave and De-Pinho 2003). This inhibition can occur due to osmotic effect, as the osmotic potential of the growth medium decreases, the availability of water to the plant decreases, or due to the

ion toxicity as the toxic ions (e.g Na^+, Cl^-) increase in the seed (Khayatnezhad *et al*. 2010; Salama, Mansour, and Hassan 2011; Homayoun 2011). Therefore, this experiment aimed to determine the effect of priming treatments on seed osmotic balance (osmotic effect and ionic effect).

6.7.1. Material and Methods

The seed recovery test was under taken using the primed and unprimed seeds that did not germinate under saline stress within the scheduled time. Non-germinated seeds from each treatment were removed and washed with distilled water to remove any salts on the surface of the seeds. Seeds were put in 9 cm diameter Petri dishes containing two Whatman No.1 filter papers. 10 ml of distilled water was added to each Petri dish. All Petri dishes were covered with lids and closed with parafilm to avoid any evaporation and were put in a growth incubator at 25°C for ten days. Germinated seeds were removed daily and the experiment was terminated at day ten. The final germination recovery percentage was calculated using the following formula (Khan, Gul and Weber 2000; Qu *et al*. 2008):

$$\text{Recovery \%} = [(A - B) / (C - B)] \times 100$$

Where:

A = the total number of germinated seeds in salt solutions and in distilled water.

B = the number of seeds germinated in salt solutions.

C = the total number of tested seeds.

The final germination recovery percentage was arcsine transformed and then statistically analysed using three way ANOVA.

6.7.2. Results

Three way ANOVA showed that the effects of cultivar and NaCl concentration, and the interaction between cultivar and NaCl concentration on seed recovery were significant ($p < 0.05$).

Table 6.42. The significance of interactions between treatments using ANOVA for Germination Recovery.

Treatment Combination	Significant or not	P
Cultivar	S	<0.01
Priming	NS	0.07
NaCl concentration	S	<0.01
Cultivar*Priming	NS	0.83
Cultivar*NaCl Concentration	S	0.02
Priming* NaCl Concentration	NS	0.93
Cultivar*Priming* NaCl Concentration	NS	0.41

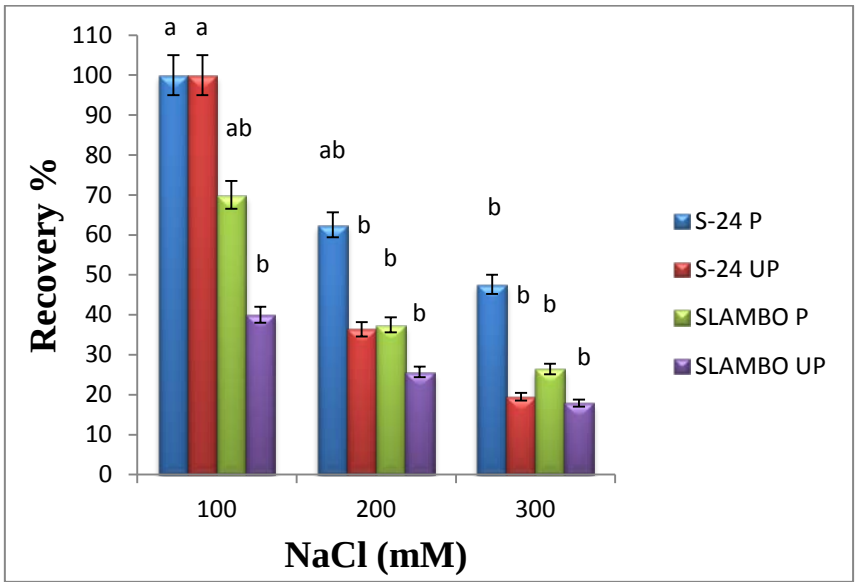

Figure 6.2. Effect of different salinity levels on seed recovery of primed seeds with $CaCl_2$ and unprimed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, n=5).

Figure 6.2 showed that better recovery was observed at lower concentration of NaCl. At 100 mM of NaCl, the results of recovery test applied to the non-germinated seeds show that the

seeds of cv. S-24 showed up to 100% recovery in primed and unprimed seeds, compared to 46% in unprimed and 73% in primed seeds of cv. Slambo. At 200 mM of NaCl the recovery range was from 30% in unprimed seeds to 50% in primed seeds of cv. S-24, and from 25% in unprimed seeds to 38% in primed seeds of cv. Slambo. At the highest level of salinity (300 mM) the recovery percentage ranged from 20% in unprimed seeds to 37% in primed seeds of cv. S-24 and from 18% in unprimed seeds to 27% in primed seeds of cv. Slambo. Moreover, the germination recovery did not differ significantly between cultivars across all NaCl concentrations whether seeds were primed or not except at 100 mM with unprimed seeds.

6.7.3. Discussion

It was noted that better recovery percentage was observed in seeds soaked in lower salinity concentrations **(**Figure 6.2) and this is probably as a result of less accumulation of ions (Na^+, Cl^-) because seeds soaked in 100 mM of NaCl accumulated less Na^+ than those soaked in higher NaCl concentration (Table 6.30). Similarly, Wahid (2001), Rahman *et al*. (2008), Khayatnezhad *et al*. (2010) and Homayoun (2011) also attributed greater seed recovery to a low Na^+ accumulation in seeds.

The decrease of seed recovery percentage due to the effects of salinity is supported by the results of Gulzar, Khan, and Ungar (2001), Qu *et al*. (2008) and Homayoun (2011) who found that seed recovery percentage declines as salt concentration increases. Rahman *et al*. (2008) studied the effect of salinity on seed recovery of four wheat cultivars and the results showed that the recovery percentage declined with an increase in salinity. The results also indicated that there was variation among cultivars in terms of their response to the recovery test. Similarly Khayatnezhad *et al*. (2010) tested the effect of a range of salinity from -2 to -10 bars on five wheat cultivars and these results also suggested that the recovery percentage declined as the salinity level increased.

It has been claimed that a high concentration of ions in the saline solution decreases the osmotic potential which in turn generates a water deficit where water uptake is inhibited or induces toxic effect due to excessive accumulation of Na^+ and / or Cl^- in the plant tissue (Munns 2005; Munns and Tester 2008). Kikuchi *et al*. (2006) and Abebe and Modi (2009) noted that water uptake is considered important for a number of processes such as enzyme activation, which supports mobilization and translocation of reserves and ensures the supply of nutrient to the embryo and generates energy for the initiation of active germination and seedling development. Thus, the greater recovery of primed and unprimed seeds of cv. S-24 at 100 mM NaCl may suggest that inhibtion of germination was due to an osmotic effect that prevented water uptake. This can be confirmed by the reduction of water uptake with increased NaCl level (Table 6.25). Lakhdar *et al*. (2008), Mohammadi (2009) and Akbarimoghaddam *et al*. (2011) reported that the external osmotic potential is decreased with the increase of salinity level in the growth medium and this inhibits the water uptake by seeds.

Reduction of seed recovery percentage of seeds that were incubated in high salt concentrations could also be due to high accumulation of ions (Na^+, Cl^-) which may cause toxicity to the embryo and thus seed death (Wahid 2001; Rahman *et al*. 2008; Khayatnezhad *et al*. 2010; Homayoun 2011). It has been reported that the ratio of K^+: Na^+ in determining relative toxicities of ions and can provide insight into ion antagonisms (Cramer, Alberico, and Schmidt 1994). Salinity negatively affects the ratio of K^+: Na^+ and probably caused injury to embryos (Rahman *et al*. 2008). Furthermore, salinity also induced seed membrane damage due to increased Na^+ accumulation. Therefore, a reduction in seed recovery may also be due to accumulation of Na^+ in seeds. This is confirmed by enhanced Na^+ concentration in seeds (Table 6.30).

The capacity of cellular membranes to repair any damage affects seed electrolyte leakage (Hampton 1995). The more rapidly membranes repair, the lower the level of ion leakage and the higher the seed vigour. The slower membranes repair the greater the ion leakage and the lower the seed vigour (International Seed Testing Association 2003). Moreover, the increase of ion leakage due to salt stress is also a sign of membrane damage (Hampton 1995). Consequently, a low percentage of recovery could be due to the adverse impact of high levels of Na^+ on the membrane, which increased ion leakage. This hypothesis can be supported by the effect of salinity on the ion leakage (Figure 6.1).

It can be concluded that better germination recovery at lower salinity level could be due to the osmotic adjustment of the seeds. However, the inhibition in germination at a high level of salinity could be as a result of a high accumulation of Na^+ ions in the seed tissue causing toxicity.

6.8. Chapter Conclusion

The increase of NaCl concentration in the growth medium solution reduced the plant germination and growth. Application of 30% GC gave a better emergence and growth improvement. The addition of Ca^{2+} with the amount as found in 30% GC enhanced all the investigated growth parameters of both cultivars better than all other treatments. Moreover, both compost treatments (30% GC and 30% mix) significantly improved the water holding capacity of the soil. Furthermore, priming treatment with $CaCl_2$ significantly improved the seed water uptake, seed membrane integrity, ion content especially Ca^{2+}, and the germination recovery.

Results suggest that the beneficial effects of the combination of priming and compost on plant growth can be reproduced by increasing the Ca^{2+} concentration in the plants by the application of priming with $CaCl_2$ and the addition of 30% GC as both of them enhanced the

concentration of Ca^{2+} and the availability of water for the germination and emergence of the plant.

Chapter 7
General Discussion

7.1. The effect of salinity

Salinity is a serious threat to crops, especially in regions where agricultural practice is largely based on irrigation (Flowers 2004; Atak *et al*. 2006). Of all crop growth stages seed germination and early seedling establishment are the most sensitive phases to salinity (Atak *et al*. 2006). The results of this study revealed that, regardless of treatment, the germination, emergence percentage and the growth of both cultivars, S-24 and Slambo, decreased in response to NaCl. A negative effect of salinity on plant growth is commonly reported in the literature. A negative correlation between shoot and root length and fresh and dry weight of shoots and roots and salinity concentrations has been reported in many investigations and was also observed in this study.

The inhibition in germination and growth may be due to either the increase of Na^+ ions leading to a reduction in the water potentialin the growth media which decreases the availability of wateror due to the increase of NaCl toxicity as a result of the high accumulation of Na^+ in the plant tissue (Eleiwa, Bafeel and Ibrahim 2011).

7.2. Germination

The results of priming experiments (Section 3.2) showed that priming with $CaCl_2$ was the only priming treatment that improved germination significantly in both cultivars and under all NaCl concentrations. Seeds primed with $CaCl_2$ performed better than unprimed seeds in both wheat cultivars. Many researchers have suggested that priming with $CaCl_2$ is the most effective priming treatment for enhancing the germination (Basra *et al*. 2005; Rafiq *et al*.

2006; Afzal *et al*. 2008). The results indicated that treatment of cv. Slambo and cv. S-24 with H_2O, KCl or NaCl had a minimum effect compared to $CaCl_2$. The failure of H_2O, KCl or NaCl as priming agents to enhance the germination percentage, germination rate and mean germination time of both wheat cultivars under both saline and non-saline conditions confirms that cultivars may differ in their response to priming agents and the choice of priming media is one of the critical factors which affects priming success. These are in agreement with findings from Yari, Aghaalikani, and Khazaei (2010) with KCl, Afzal *et al*. (2006a) with H_2O, and Afzal *et al*. (2007b), Afzal *et al*. (2008), and Basra *et al*. (2005) with NaCl.

The results also showed that in both wheat cultivars there was no emergence at 300 mM in the greenhouse (Table 3.9) but germination was recorded at the same NaCl concentration in the laboratory experiment (Table 3.2). It can be suggested that the inhibition of emergence at 300 mM NaCl was due to the fact that the length of the radicle in the emergence experiment did not reach 2 cm, which was the sowing depth, in order to appear at the soil surface. Also due to the frequency of the irrigation with saline water, toxicity may have occurred causing radicle death, while seeds were considered germinated in the laboratory experiment when the radicle reached 2 mm length. MET was not affected by the increase of salt level in primed seeds but this effect was significant at 200 mM in unprimed seeds of both cultivars.

Compost can play a significant role in soil fertility. Compost has important physical and chemical properties. The increased and enhanced change in physical and chemical properties of sand relies on the amount of compost used. Minhas (1996) reported that the negative impacts of salinity on the physical and chemical properties of soil can be mitigated by the application of different amendments, which contain soluble calcium. As sand structure is enhanced due to the application of compost, the permeability, water holding capacity and the

availability of nutrients of sand are also improved (Brady and Weil 1999). Furthermore, compost has two principle beneficial effects in reclamation of saline soil, these are (1) enhancement of soil structure and permeability, thus improving salt leaching and (2) decreasing the evaporation from the surface of the soil and inhibition of salt accumulation in the top of the soil, and release of carbon dioxide during respiration processes (Lakhdar *et al*. 2009). Moreover, compost has a positive effect on the pH of sand (Maynard 1997), as pH of sand increased to the neutral level when compost was added.

The results of the compost experiment (Section 4.7) indicated that 30% GC was the most successful compost treatment that reduced the harmful effect of salinity and improved the E%, ER and MET of both wheat cultivars under all NaCl concentrations followed by 30% mix at 200 mM. 30% GC was also the only compost treatment that enabled emergence of seedlings at 300 mM NaCl (Table 4.5). However, other forms of compost proved to be effective only for some investigated parameters and NaCl concentrations. The beneficial effect of compost was observed at different levels of NaCl. A positive effect of compost on E%, ER and MET has been reported by Lawson, Hayatsu, and Nioh (2004), Tilston *et al*. (2005) Ibrahim *et al*. (2008). The results also indicated that treatment of cv. Slambo and cv. S-24 with 30% CC, 10% CC, 10% GC and 10% mix were not worthwhile because their effects were not significant for almost all growth parameters for both wheat cultivars as compared to controls.

The combination of priming and compost alleviated the adverse impact of salinity on the investigated parameters (Chapter 5). The results showed that the combination of priming with $CaCl_2$ and 30% GC was the most effective in increasing the E%, ER and MET of both cultivars followed by the combination of priming with $CaCl_2$ and 30% mix compared to the untreated control. The results of the combination experiment (Section 5.1) showed that priming with $CaCl_2$ not only improved the emergence of seeds grown in 30% GC but also

helped seeds sown in 30% mix to emerge at 300 mM NaCl as unprimed seeds grown in 30% mix failed to emerge at 300 mM. This can be attributed to the increase of Ca^{2+} due to the application of priming and compost, as 30% mix had lower Ca^{2+} than 30% GC. Table 7.1 shows the increase in emergence as a result of the applied treatments as compared to the control.

Table 7.1. The increase in emergence percentage of cv. Slambo and cv. S-24 due to different treatments (- = no increase).

Cultivar	Treatment	The increase in percentage NaCl (mM)				Source
		0	100	200	300	
Slambo	P	2.0	21.0	14.0	*	(Table 3.9)
	30% GC	_	21.7	66.7	26.6	(Table 4.5)
	P + 30% GC	8.0	27.0	65.0	43.0	(Table 5.2)
S-24	P	1.0	20.0	24.0	*	(Table 3.9)
	30% GC	5.0	15.0	51.7	46.6	(Table 4.5)
	P + 30% GC	10.0	27.0	61.0	49.0	(Table 5.2)

Table 7.1 showed that in both wheat cultivars, the increase in emergence in seeds sown in 30% GC was considerably higher than those seeds subjected to priming alone especially under high NaCl concentrations. However, the increase in percentage emergence of seeds subjected to priming and 30% GC was considerably higher than those seeds subjected to 30% GC alone only at 300 mM in cv. Slambo and at 100 and 200 mM in cv. S-24.

7.3. Seedling Growth

Priming with $CaCl_2$ improved the growth parameters such as shoot and root length, fresh and dry weight of shoots and roots in both wheat cultivars. This enhancement in growth parameters is in line with the findings of Basra *et al*. (2005), Rafiq *et al*. (2006), and Iqbal and Ashraf (2007). Priming has also proved to be useful in long term experiments with wheat. Furthermore, on-farm seed priming has been reported to improve crop growth under

saline conditions. Abro, Mahar, and Mirbahar (2009) studied the effect of on-farm seed priming with water on six wheat cultivars during autumn 2005 – 2006. They reported that on-farm seed priming improved the emergence and overall grain yield significantly suggesting that priming can be a valuable method to improve wheat yield under salinity stress. Moreover, Rehman *et al* (2011) studied the effect of on-farm seed priming with H_2O and $CaCl_2$ on the growth of super basmati rice for about three months and the results showed that seed priming with $CaCl_2$ was the most effective in improving seedling establishment and yield as compared to the control.

The results also showed that 30% GC was the only compost treatment that significantly increased all growth parameters under all NaCl concentrations except root fresh weight which was not affected by compost treatment at all NaCl concentrations. This inhibition in root fresh weight may be due to the high accumulation of Na^+ in root tissue. Khayatnezhad *et al*. (2010) reported that salinity depressed root growth more than shoot growth. Sarwar *et al*. (2007) studied the effect of two levels of greenwaste compost (12 and 24 t ha^{-1}) on wheat and the results showed that at maturity the grain yield and yield components such as plant height, number of fertile tillers and 1000 grain weight of wheat improved significantly with the use of organic material in the form of compost at both treatment levels. The results showed that grain yield of wheat was 2.56 t ha^{-1} in the control and increased to 4.27 and 4.59 t ha^{-1} when 12 and 24 t ha^{-1} of compost were used, respectively. Moreover, Ibrahim *et al*. (2008) studied the effect of different levels of greenwaste compost (300, 400 and 500 kg ha^{-1}) on the growth of wheat. At maturity, the results showed that compost significantly improved the plant height, number of tillers, spike length, straw/grain yield and 1000 grain weight as compared to control. For instance, the maximum increase (16% over control) in plant height was recorded when compost was added at 500 kg ha^{-1}. Furthermore, in both wheat cultivars, the

combination of priming and 30% GC was the best combination treatment that improved all growth parameters under all NaCl concentrations.

This enhancement in growth parameters of both wheat cultivars due to priming application may be due to the effect of Ca^{2+} on membrane repair of seeds (Afzal *et al*. 2008), which can be confirmed by the enhancement of seed ion leachate (Section 6.5) or, it may be due to the effect of Ca^{2+} on Na^{+} absorption (Rafiq *et al*. 2006), which can be confirmed by the effect of priming on seed ion uptake (Section 6.6), or it may be due to the increase in water uptake rate and earlier initiation of metabolic processes (Saglam *et al*. 2010), which can be confirmed by the effect of priming with $CaCl_2$ on seed water uptake (Section 6.4). This improvement may also be due to the effect of Ca^{2+} on cell wall structure and cell division rate (Patade, Bhargava, and Suprasanna 2009) or due to the increase in the synthesis of DNA, RNA and proteins which are important for radicle growth (Afzal *et al*. 2007b; Farooq *et al*. 2010b). Moreover, the positive effects of compost on growth of both cultivars maybe due to its chemical and physical characteristics, as compost enhances water status and supplies nutrients such as N, Ca^{2+}, and K^{+}, thus reducing the effect of NaCl stress on the plants (Su *et al*. 2003). This can be explained by the effect of compost on water holding capacity (Section 6.3), and also by the chemical analysis of compost (Section 4.2). It may also be due to the effect of Ca^{2+} on the cell division rate as GC had a significantly higher Ca^{2+} than CC (Table 4.1). Moreover the enhancement in the emergence of both cultivars might also be due to the effect of nitrogen as nitrogen plays a crucial role in both photosynthesis and protein synthesis (Zekri and Obreza 2009), as well as synthesis of plant chlorophyll and DNA and RNA (California Foundation for Agriculture 2009). Furthermore, as a result of getting separate benefits from priming and compost, the combination of them improved the growth of both cultivars as priming helped seeds in the first stage of emergence and compost continuously provides the radicle with nutrients and available water.

7.4. The Roles of Calcium

Calcium is an important ion for the growth of plants in saline and non-saline soils. Gobinathan, Murali and Panneerselvam (2009) suggested that Ca^{2+} plays an essential role in plant cell division and elongation, structure and permeability of cell membranes, carbohydrate translocation and enzymatic activities. The presence of Ca^{2+} decreases the harmful effects of salinity on the growth of a plant (Rehman *et al*. 2000). It has been reported that Ca^{2+} mitigates the plant uptake of Na^{+} (Parida and Das 2004; Shaikh *et al*. 2007). The results showed that priming with $CaCl_2$ decreased the uptake of Na^{+} especially with cv. S-24 (Section 6.6). Moreover, Ca^{2+} is a vital element for the maintenance of membrane integrity (Cramer 2002, Gobinathan, Murali and Panneerselvam 2009). Afzal *et al*. (2007a), Afzal *et al*. (2007b), and Khan *et al*. (2010) reported that the reduction in seed leakage was due to the effect of Ca^{2+} on membrane repair rate. Section 6.1 showed that priming with $CaCl_2$ reduced the leakage of both cultivars under all NaCl concentrations. Furthermore, Ca^{2+} has been reported to play an important role in regulating the uptake of nutrients across cell membranes (Cramer 2002). The results showed that priming with $CaCl_2$ enhanced the uptake of nutrients (Section 6.6). In addition, Ca^{2+} plays a critical role in enhancing water uptake as Ca^{2+} is considered as an important osmotic adjustor under saline conditions (Summart *et al*. 2010). It has been claimed that the absorbtion of Ca^{2+} leads to a decrease in the osmotic potential of the plant thus increasing the uptake of water (Ashraf 2004). The results showed that water uptake of both wheat cultivars was increased under all NaCl levels when priming with $CaCl_2$ were used (Section 6.4).

7.5. Priming

The demand for food is increasing as the world population increases (Ashraf *et al*. 2008). Whilst this can be met by increasing the area of cultivated land, a high percentage of

cultivated lands are affected by salinity (Haidarizadeh and Zarei 2009). Therefore, improving the salt tolerance of crops to be grown in such environments is essential (Ashraf *et al*. 2008). Several techniques have been developed to tackle the problem including pre-sowing treatments scientists know as priming. This technique is a treatment that is applied before germination in a specific environment such that seeds are partially hydrated to a point where germination processes begin but radical emergence does not occur (Sadeghi *et al*. 2011).

Seed priming has been successfully demonstrated to improve germination and emergence in seeds of many crops in the arid and semi-arid tropics especially under saline conditions (Yari *et al*. 2011). Compared with other strategies, priming is an easy to use, low cost and low risk technique and the approach has recently been used to overcome the salinity problem in agriculture lands (Tavili *et al*. 2011). In Libya, for instance, organic and inorganic salts are available and provided for farmers and research activities by the Libyan Research Center or the Libyan Provider Agriculture Company. The cost of most salts is affordable to all farmers and the cost for $CaCl_2$ (Powder 250 g) is 12 LYD which is about £5.50 with conversion rate of the last six monthes of £1 equals 1.97 LYD (Xrates 2013). Furthermore, wheat in Libya costs about 145 LYD for a bag of 100 kg which is about £72.50. According to wheat - planting information (2013) the sown rate of wheat is 38 kg h^{-1}, which cost the farmers about 55.1 LYD (£25) ha^{-1}.

The results of this study suggested that in both wheat cultivars, the economic beneficial effect of halopriming with $CaCl_2$ on the emergence of seeds occurred at 100 mM NaCl where priming significantly affected the emergence of both cultivars. Moreover, the significant effect of priming with $CaCl_2$ on growth parameters such as shoot and root length, and fresh and dry weight of shoots and roots was recorded at 0 and100 mM (Section 3.3). However, even though priming with $CaCl_2$ significantly increased the emergence and growth of almost all the measured parameters at 200 mM compared to unprimed seeds this increase is not

economically valuable as the actual emergence percentage is still low. Therefore, due to the availability of $CaCl_2$ to farmers in Libya, this method can be effectively adopted by the Libyan farmers for use in lands where the salinity level does not exceed 100 mM NaCl. At 0 mM NaCl the results suggested that there would be no economic benefit of halopriming with $CaCl_2$ if the target of sowing is grain production in both wheat cultivars, as primed and unprimed seeds did not differ significantly in emergence but this effect become economically beneficial even at 0 mM if the purpose of sowing is to produce feed for livestock as primed seeds had a significantly greater shoot length and significantly higher fresh and dry weight of shoots. Thus, at 0 mM the application of priming depends on the purpose of sowing.

7.6. Compost

Crops grown under salt stress exhibit disrupted metabolism culminating in stunted growth and poor productivity. One possible way to reduce the effect of salt stress is the application of compost (Lawson, Hayatsu and Nioh 2004). The importance of compost is well known due to its multiple functions in soil. Compost can be beneficial not only to enhance organic matter, physical and chemical properties of soil, water holding capacity, and aeration in soil but also to provide plant nutrients (John, Khalid and Javed 1998). In Libya, greenwaste compost is available to farmers and provided by the Libyan Provider Agriculture Company. One tonne of greenwaste compost costs 75 LYD which is about £37.50. On this basis the cost of providing compost as a soil amendment in the field at 30% and 10% by weight can be calculated based on a standard acre furrow slice, adapted for any area of 1 ha.

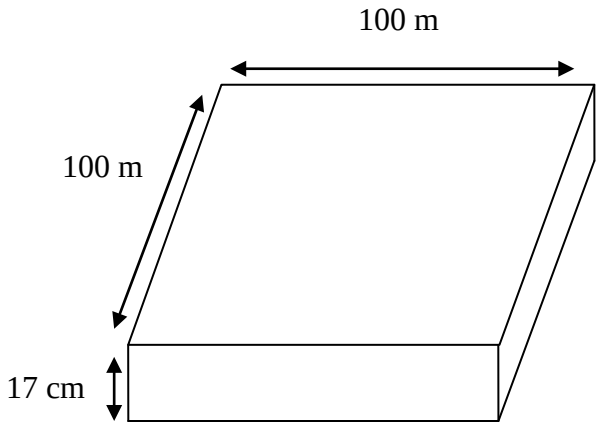

Figure 7.1. Dimension of the measurement of one hectare

$100\ m \times 100\ m \times 0.17\ m = 1700\ m^3$

The density of sand soil (ρ) = 1.6 g cm^3

$\rho = m / v \implies m = \rho \times v$

Where:

ρ is the density of the soil

m is the mass of the soil

v is the volume of the soil

mass of the soil = $1700\ m^3 \times 1600000\ g\ m^3 = 2720000000\ g / 1000000 = 2720$ tonnes

30% = $2720 \times 0.33 = 897.6$ tonnes

10% = $2720 \times 0.1 = 272$ tonnes

Therefore, treating one hectare will cost the farmer £33600 (30% compost) + £27.36 (wheat cost) = £33627.36 when 30% GC is used. However, it will cost £10200 (10% compost) + £27.36 (wheat cost) = £1227.36 when 10% GC were used.

This study showed that 30% GC significantly increased seed emergence of both wheat cultivars under 200 and 300 mM NaCl. 30% GC effectively increased the emergence of both wheat cultivars at 200 mM NaCl more than all other treatments except 30% mix and their performance was economically valuable and significantly equal to the emergence in non-saline control in both wheat cultivars. In addition, at 300 mM 30% GC was also the only compost treatment that enabled emergence in both wheat cultivars but this emergence is not economically valuable for farmers as the emergence percentage was less than 50% of the total sowing seeds**.** However, the density of plants was significantly lower in sand than in 30% GC (Table 4.11) and shoot length of both cultivars was significantly higher in 30% GC than in sand at 100 and 200 mM NaCl. Experimentally 30% GC can be used in soils where the level of salinity does not exceed 200 mM but economically this regime could not be adopted by Libyan farmers because it needs a considerable amount of compost (897.6 t ha^{-1}) which is very costly. For the soils in which salt level is less than 100 mM, the results suggested that there is no benefit from using compost as the emergence in sand was not significantly different from all compost treatments in both wheat cultivars (Table 4.5).

The interaction of priming and compost effectively enhanced the emergence and growth of both wheat cultivars. However, for the emergence, there was no effect of the combination of priming and compost on the emergence of cv. Slambo at 0 mM but the effect was significant in cv. S-24 (Table 5.2). Thus the results suggest that in non-saline soils, there is no need to use the combination when sowing cv. Slambo as seeds sown in sand had an emergence which was not significantly different from other treatments (Table 5.2) but the combination of priming with $CaCl_2$ and 30% GC is useful when sowing cv. S-24 in non-saline soils. The results also suggest that for both wheat cultivars, the combination of priming with $CaCl_2$ and 30% GC results in a significantly higher emergence than in sand at 100 mM but economically priming with $CaCl_2$ can be used by the farmers in lands characterized with

salinity level does not exceed 100 mM as there was no significant difference between priming alone and the combination of priming and 30% GC at 100 mM. Moreover, the performance of cv. Slambo and cv. S-24 primed seeds with $CaCl_2$ is enhanced and become worthy at 200 mM when they sown in compost especially in 30% GC where the emergence increased to 76% in cv.Slambo and 84% in cv. S-24 (Table 5.2). Moreover, for the growth of both wheat cultivars primed seeds with $CaCl_2$ grown in 30% GC was the best treatment that had a significantly higher growth as shoot length and fresh and dry weight were significantly higher the in control but in the field this regime could not be adopted by Libyan farmers as a high amount of compost is required.

7.7. Conclusion

It can be concluded that in non-saline soils, all the treatments failed to increase the emergence significantly in both wheat cultivars except with cv. S-24 with primed seeds sown in 30% GC. Moreover, at 100 mM the combination of priming with $CaCl_2$ and 30% GC, and priming with $CaCl_2$ alone were the only two treatments that increased the emergence of both wheat cultivars significantly as compared to control but the difference between them was not significant therefore, priming with $CaCl_2$ alone is suggested to be used in lands where the salinity does not exceed 100 mM as it cost lower than when the 30% GC is used. In the greenhouse, for cv. Slambo, 30% GC is recommended to be used as there was no significant difference between 30% GC and the combination of priming and 30% GC in terms of emergence but both of them were significantly higher the controlwhen salinity is about 200 mM. For cv. S-24 the combination treatment of priming and 30% GC is recommended to be applied in the greenhouse as it had a significantly higher emergence than all other treatments. At 300 mM all the treatment failed to increase the emergence and growth of both cultivars and it can be suggested that more tolerance cultivars to be used in order to reach reasonable

emergence and growth. Economically, in the field 10% and 30% of compost can not be adopted by Libyan farmers as a high amount of compost is required which is very costly.

Chapter 8
Conclusion, recommendations and future work

8.1. Conclusion

It can be concluded that the increase of NaCl concentrations had harmful effects on the germination, emergence and seedling growth of both cultivars. Priming with 50 mM of $CaCl_2$ proved to be the most effective treatment that improved germination and emergence percentage and rate, and all the growth parameters under salt stress. Furthermore, 30% GC followed by 30% mix also proved to be the best compost treatments that improved almost all growth parameters under NaCl concentrations. Moreover, the combination between primed seeds with $CaCl_2$ sown in 30% GC proved to enhance almost all growth parameters better than individual treatment followed by unprimed seeds sown in 30% GC and primed seeds sown in 30% mix. This improvement is attributed to the improvement in water uptake and the availability of nutrients especially Ca^{2+}. As the concentration of Ca^{2+} in GC was significantly higher than in CC. The Ca^{2+} supplement with the same concentration found in 30% GC enhanced the emergence and seedling growth of both cultivars better than all other treatments. Also this improvement can be attributed to the enhancement of water holding capacity due to the application of either 30% GC or 30% mix.

The improvement can also be attributed to the effect of priming with 50 mM of $CaCl_2$ on membrane integrity as priming improved seed ion leachate, and can be due to the enhancement of seed water uptake, and seed ion uptake.

Although, in gereral there was no significant difference between both cultivars differences were found for some parameters measured. For example, in the effect of priming treatments on the germination rate of unprimed seeds (Table 3.4), the effect of priming with $CaCl_2$ on the emergence at 200 mM (Table 3.9), the effect of compost treatments on the root

length at 300 mM (Table 4.13), and in the effect of the combination of priming and compost on the shoot length (Table 5.8). Both cultivars were able to grow at 200 mM in sand and at 300 mM when a combination of priming and compost was used. Overall as compared to cv. S-24, cv. Slambo can be considered as a salt tolerant cultivar.

8.2. Recommendations

The research reveals that either priming with 50 mM $CaCl_2$, 30% GC or a combination of both are effective in improving the performance of both tested cultivars under saline conditions. Therefore, in same eastern regions where the salinity level is about 200 mM, it is recommended to adopt priming regimes either by local farmers or in large scale agriculture. However, in other eastern regions and in Sebrata and Misrurata where the salinity level is greater than 200 mM it is recommended to introduce other cultivars or crops that are more tolerant.

This study indicates that better performance of seeds treated by 30% GC is due to improved nutrient availability and / or better water holding capacity, thus it is recommended to adopt this method to grow these cultivars in dry areas or lands characterized with low precipitation where irrigation is used frequently to sustain growth and development. This will reduce the frequency use of irrigation and to preserve the water table.

8.3. Future work

The implementation of this research indicated that the performance of both wheat cultivars namely cv. Slambo and cv. S-24 under saline conditions was significantly improved by priming and / or 30% GC. Some mechanisms that are hypothesized to be responsible for this effectiveness were investigated but other possible factors were not. In order to get a clearer

idea of the mechanisms by which these treatments influenced their performance, there are several issues should be investigated including the following:-

- Repair of damage to DNA, proteins, and lipids is crucial in germination. Thus, since priming with $CaCl_2$ improved the salt tolerance of both cultivars, it might be beneficial to investigate the effect of priming on possible repair of damage to DNA, proteins, and lipids.

- The food reserves within seeds cannot be utilized for germination unless they are broken into utilizable structures. For instance, in order to use starch for growth, seeds must convert it into maltose via the enzyme amylase. However, salinity has been reported to inhibit enzymatic activity. Thus, it is beneficial to investigate the effect of priming on the enzymatic activity that has been reported vital for seed performance in saline environment.

- It has been claimed that in order to sustain water uptake, plants grown in saline conditions must uptake ions to utilize them in osmotic adjustment. Na^+, Cl^-, K^+ and Ca^{2+} are among these ions. However, while Na^+ and Cl^- may achieve osmotic adjustment, they might be toxic (Flowers, Galal, and Bronhmam 2010). Marchner (1995) claimed that number of plants are sensitive to Cl^-, thus, this ion should also be determined as it might be a supporting factor of the beneficial effect of either priming or the implementation of compost.

- Check chemical compostion of range of greenwastes in Libya to find which has optimum levels of nutrients.

- Other physiological parameters such as water status, leaf osmotic potential, leaf water potential, and leaf water turgor should also be determined as they reflect the performance of plants grown under salt stress.

- Whilst osmotic adjustment can be achieved by the accumulation of inorganic ions K^+, Ca^{2+}, Na^+ and Cl^-, it can also be achieved by the production of organic compounds especially proline and glycine betaine. Therefore, determination of organic solutes may complete the view of how priming and or 30% GC improved the performance of these two cultivars in saline gradients.

- The effect of priming and compost on the drought tolerance of these two cultivars can also be examined.

- It is also essential to implement field trials for the best combination of treatment in Libya to ensure its results and the laboratory results as well.

Chapter 9

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APPENDICES

A 1. Results of Primary germination experiments.

A1.1. Seed Vigour Test.

Table A.1. Vigour test of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) seeds germinated in distild water (mean values, range in brackets, n = 5).

Cltivar	Germination (%)
S-24	98(96-100)
Slambo	97(95-98)

A 1.2. The Effect of Priming on the Germination.

Table A.2. Three-way analysis of variance for G% of cv. Slambo

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	8	5100.0	5100.0	637.5	21.20	0.000
Concentration	3	31125.8	31125.8	10375.3	345.03	0.000
Treatment*Concentration	24	1188.3	1188.3	49.5	1.65	0.55
Error	72	2165.1	2165.1	30.1		
Total	107	39579.3				

Table A.3. Three-way analysis of variance for G% of cv. S-24

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	8	6333.3	6333.3	791.7	36.93	0.000
Concentration	3	31162.5	31162.5	10387.5	484.56	0.000
Treatment*Concentration	24	1720.6	1720.6	71.7	3.34	0.000
Error	72	1543.5	1543.5	21.4		
Total	107	40759.9				

Table A.4. Effect of different salinity levels on germination percentage (G%) of primed and non-primed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, range in brackets, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	UP	95^{a}(90-100)	83^{abcde}(80-85)	58^{efgh}(40-75)	28^{ijkl}(15-35)
	Hydro	95^{a}(90-100)	90^{abc}(90-90)	63^{defg}(60-65)	31^{hijkl}(30-35)
	Mannitol	90^{abc}(85-95)	90^{abc}(85-95)	56^{efghi}(55-60)	16^{kl}(15-20)
	KCl	96^{a}(95-100)	93^{abc}(90-95)	80^{abcde}(75-85)	48^{fghij}(45-50)
	$CaCL_2$	96^{a}(95-100)	95^{a}(90-100)	88^{abcd}(85-90)	63^{defg}(60-65)
	K_2SO_4	93^{abc}(90-95)	88^{abcd}(85-95)	58^{efgh}(55-60)	21^{jkl}(20-25)
	$MgSO_4$	91^{ab}(85-100)	81^{abcde}(75-90)	43^{ghijk}(40-45)	16^{kl}(15-20)
	$ZnSO_4$	80^{abcde}(75-85)	75^{bcdef}(55-85)	41^{ghijkl}(35-45)	15^{l}(10-20)
	NaCl	93^{abc}(90-95)	91^{abc}(90-95)	71^{cdefg}(70-75)	28^{hijkl}(25-30)
S-24	UP	98^{ab}(95-100)	93^{abcd}(90-95)	65^{ghij}(60-70)	31^{klmn}(30-35)
	Hydro	96^{abc}(95-100)	93^{abcd}(90-95)	75^{efgh}(70-80)	41^{jklm}(40-45)
	Mannitol	91^{bcde}(90-95)	85^{cdefg}(80-90)	45^{ijkl}(40-50)	13^{n}(10-15)
	KCl	96^{abc}(95-100)	86^{cdef}(85-90)	81^{defg}(80-85)	51^{hijk}(45-55)
	$CaCL_2$	100^{a}(100-100)	96^{abc}(95-100)	90^{bcde}(85-95)	68^{fghi}(60-80)
	K_2SO_4	95^{abcd}(90-100)	83^{defg}(80-85)	50^{hijk}(45-55)	23^{lmn}(20-25)
	$MgSO_4$	95^{abcd}(90-100)	86^{cdef}(80-95)	45^{ijkl}(45-45)	21^{lmn}(20-25)
	$ZnSO_4$	88^{bcdef}(80-95)	73^{efgh}(70-75)	43^{ijkl}(40-45)	18^{mn}(15-20)
	NaCl	95^{abcd}(95-95)	86^{cdef}(80-95)	81^{defg}(80-85)	35^{klmn}(30-40)

Statistical analysis was done for each cultivar separately.

Table A.5. Three-way analysis of variance for GR of cv. Slambo

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	8	0.453418	0.453418	0.056677	56.93	0.000
Concentration	3	2.453263	2.453263	0.817754	821.37	0.000
Treatment*Concentration	24	0.049151	0.049151	0.002048	2.06	0.010
Error	72	0.071683	0.071683	0.000996		
Total	107	3.027514				

Table A.6. Three-way analysis of variance for GR of cv. S-24

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	8	0.537827	0.537827	0.067228	72.07	0.000
Concentration	3	2.231648	2.231648	0.743883	797.50	0.000
Treatment*Concentration	24	0.030450	0.030450	0.001269	1.36	0.160
Error	72	0.067160	0.067160	0.000933		
Total	107	2.867084				

Table A.7. Effect of different salinity levels on germination rate (GR) ($1/T_{50}$) of primed and non-primed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, range in brackets, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	UP	0.61^{ab}(0.61-0.61)	0.53^{abcd}0.52-0.55)	0.28^{jklmn}(0.24-0.31)	0.18^{nopq}(0.14-0.21)
	Hydro	0.62^{ab}(0.6-0.65)	0.62^{ab}(0.6-0.64)	0.33^{ghijkl}(0.3-0.36)	0.21^{nopq}(0.2-0.24)
	Mannitol	0.53^{bcd}(0.51-0.55)	0.42^{efgh}(0.4-0.44)	0.25^{lmno}(0.23-0.28)	0.15^{opq}(0.12-0.17)
	KCl	0.61^{ab}(0.61-0.62)	0.57^{abc}(0.55-0.59)	0.35^{fghijk}(0.3-0.39)	0.28^{jklmn}(0.22-0.24)
	$CaCL_2$	0.64^{a}(0.63-0.64)	0.62^{ab}(0.62-0.63)	0.42^{efghi}(0.4-0.45)	0.32^{ijklm}(0.3-0.35)
	K_2SO_4	0.5^{cde}(0.44-0.56)	0.44^{def}(0.42-0.46)	0.23^{lmnop}(0.22-0.24)	0.14^{opq}(0.1-0.18)
	$MgSO_4$	0.52^{bcd}(0.5-0.54)	0.43^{defg}(0.4-0.45)	0.26^{klmn}(0.19-0.33)	0.14^{opq}(0.13-0.16)
	$ZnSO_4$	0.51^{cde}(0.45-0.54)	0.37^{fghij}(0.32-0.4)	0.22^{mnopq}(0.2-0.23)	0.12^{q}(0.12-0.13)
	NaCl	0.62^{ab}(0.61-0.62)	0.54^{abc}(0.52-0.57)	0.33^{hijkl}(0.3-0.37)	0.26^{klmn}(0.24-0.29)
S-24	UP	0.63^{ab}(0.62-0.64)	0.55^{abcd}(0.54-0.58)	0.37^{hijk}(0.33-0.4)	0.25^{lmn}(0.2-0.31)
	Hydro	0.62^{abc}(0.6-0.64)	0.57^{abcd}(0.54-0.62)	0.35^{hijkl}(0.33-0.37)	0.27^{klm}(0.2-0.32)
	Mannitol	0.52^{defg}(0.5-0.55)	0.44^{fghi}(0.44-0.44)	0.27^{klm}(0.25-0.32)	0.16^{nop}(0.14-0.18)
	KCl	0.64^{a}(0.64-0.65)	0.59^{abcd}(0.58-0.6)	0.38^{hij}(0.37-0.39)	0.3^{jklm}(0.25-0.33)
	$CaCL_2$	0.64^{a}(0.62-0.66)	0.63^{abc}(0.61-0.66)	0.45^{efgh}(0.42-0.48)	0.37^{hijk}(0.35-0.38)
	K_2SO_4	0.53^{cdef}(0.52-0.54)	0.42^{ghi}(0.4-0.45)	0.25^{lmn}(0.25-0.27)	0.15^{op}(0.13-0.16)
	$MgSO_4$	0.54^{bcde}(0.52-0.56)	0.44^{fghi}(0.44-0.45)	0.24^{mno}(0.23-0.25)	0.14^{p}(0.13-0.15)
	$ZnSO_4$	0.52^{defg}(0.5-0.54)	0.38^{hij}(0.32-0.45)	0.23^{mnop}(0.21-0.26)	0.14^{p}(0.12-0.17)
	NaCl	0.64^{ab}(0.62-0.65)	0.56^{abcd}(0.54-0.58)	0.34^{ijkl}(0.32-0.38)	0.28^{jklm}(0.21-0.35)

Statistical analysis was done for each cultivar separately.

Table A.8. Three-way analysis of variance for MGT of cv. Slambo

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	8	21.8425	21.8425	2.7303	26.19	0.000
Concentration	3	56.7996	56.7996	18.9332	181.62	0.000
Treatment*Concentration	24	10.3122	10.3122	0.4297	4.12	0.000
Error	72	7.5058	7.5058	0.1042		
Total	107	96.4601				

Table A.9. Three-way analysis of variance for MGT of cv. S-24

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	8	21.8798	21.8798	2.7350	40.24	0.000
Concentration	3	50.7248	50.7248	16.9083	248.77	0.000
Treatment*Concentration	24	8.7660	8.7660	0.3652	5.37	0.000
Error	72	4.8936	4.8936	0.0680		
Total	107	86.2641				

Table.A.10. Effect of different salinity levels on mean germination time (MGT) (day)of primed and non-primed seeds of wheat (*Triticum aestivum* L. cv. Slambo and cv. S-24) (mean values, standard errors in brackets, n = 3).

Cultivar	Treatment	NaCl Concentration (mM)			
		0	100	200	300
Slambo	UP	$2.1^{j}(0.1)$	$2.4^{hij}(0.1)$	$3.5^{defg}(0.2)$	$5.1^{ab}(0.3)$
	Hydro	$2.1^{ij}(0.1)$	$2.5^{ghij}(0.1)$	$2.9^{efghij}(0.2)$	$3.6^{cdef}(0.1)$
	Mannitol	$2.1^{ij}(0.1)$	$2.8^{efghij}(0.2)$	$3.7^{cde}(0.1)$	$5.0^{ab}(0.1)$
	KCl	$2.2^{hij}(0.3)$	$2.3^{hij}(0.1)$	$2.6^{fghij}(0.1)$	$3.2^{defgh}(0.3)$
	$CaCL_2$	$2.1^{ij}(0.4)$	$2.3^{hij}(0.1)$	$2.5^{ghij}(0.1)$	$2.8^{efghij}(0.2)$
	K_2SO_4	$2.6^{fghij}(0.2)$	$2.7^{efghij}(0.1)$	$3.6^{cdef}(0.1)$	$4.6^{abc}(0.1)$
	$MgSO_4$	$2.8^{efghij}(0.1)$	$3.1^{defghi}(0.2)$	$4.1^{bcd}(0.2)$	$5.3^{a}(0.2)$
	$ZnSO_4$	$2.7^{efghij}(0.1)$	$2.9^{efghij}(0.1)$	$3.7^{cde}(0.2)$	$4.6^{abc}(0.1)$
	NaCl	$2.2^{hij}(0.1)$	$2.7^{efghij}(0.1)$	$3.0^{efghij}(0.2)$	$3.7^{cde}(0.1)$
S-24	UP	$2.1^{op}(0.2)$	$2.3^{mnop}(0.2)$	$3.1^{efghijklm}(0.1)$	$4.2^{cd}(0.1)$
	Hydro	$2.1^{p}(0.1)$	$2.8^{hijklmnop}(0.1)$	$3.0^{fghijklmn}(0.1)$	$3.6^{defgh}(0.1)$
	Mannitol	$2.0^{p}(0.1)$	$2.8^{ijklmnop}(0.1)$	$3.7^{defg}(0.1)$	$5.1^{ab}(0.2)$
	KCl	$2.1^{op}(0.1)$	$2.1^{op}(0.1)$	$2.4^{lmnop}(0.1)$	$3.2^{efghijkl}(0.2)$
	$CaCL_2$	$2.0^{p}(0.1)$	$2.2^{nop}(0.1)$	$2.5^{klmnop}(0.2)$	$2.7^{jklmnop}(0.3)$
	K_2SO_4	$2.8^{ijklmnop}(0.1)$	$2.9^{ghijklmno}(0.1)$	$3.8^{cdef}(0.1)$	$4.7^{abc}(0.1)$
	$MgSO_4$	$2.4^{lmnop}(0.2)$	$3.3^{efghijk}(0.2)$	$3.8^{cde}(0.3)$	$5.2^{a}(0.1)$
	$ZnSO_4$	$2.5^{klmnop}(0.1)$	$3.0^{ghijklmn}(0.1)$	$3.6^{defghi}(0.1)$	$4.3^{bcd}(0.2)$
	NaCl	$2.1^{op}(0.1)$	$2.6^{klmnop}(0.1)$	$2.9^{ghijklmno}(0.1)$	$3.5^{defghij}(0.1)$

Statistical analysis was done for each cultivar separately.

A2. Determining the best pre-sowing seed treatment for improving germination of two wheat cultivars under optimum and saline conditions

Table A.11.Three-way analysis of variance for G%.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	21.7	21.7	21.7	0.44	0.506
TREATMENT	4	5405.7	5405.7	1351.4	27.68	0.000
CONCENTRATION	3	46557.0	46557.0	15519.0	317.83	0.000
CULTIVAR*TREATMENT	4	433.9	433.9	108.5	2.22	0.068
CULTIVAR*CONCENTRATION	3	1631.7	1631.7	543.9	11.14	0.000
TREATMENT*CONCENTRATION	12	3329.9	3329.9	277.5	5.68	0.000
CULTIVAR*TREATMENT*CONCENTRATION	12	456.1	456.1	38.0	0.78	0.672
Error	200	9765.7	9765.7	48.8		
Total	239	67601.7				

Table A.12.Three-way analysis of variance for GR.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.00372	0.00372	0.00372	2.53	0.113
TREATMENT	4	0.17231	0.17231	0.04308	29.30	0.000
CONCENTRATION	3	3.59231	3.59231	1.19744	814.49	0.000
CULTIVAR*TREATMENT	4	0.02079	0.02079	0.00520	3.54	0.008
CULTIVAR*CONCENTRATION	3	0.16221	0.16221	0.05407	36.78	0.000
TREATMENT*CONCENTRATION	12	0.07640	0.07640	0.00637	4.33	0.000
CULTIVAR*TREATMENT*CONCENTRATION	12	0.02645	0.02645	0.00220	1.50	0.127
Error	200	0.29403	0.29403	0.00147		
Total	239	4.34822				

Table A.13.Three-way analysis of variance for MGT.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.1020	0.1020	0.1020	1.76	0.186
TREATMENT	4	9.5162	9.5162	2.3790	40.99	0.000
CONCENTRATION	3	139.4211	139.4211	46.4737	800.80	0.000
CULTIVAR*TREATMENT	4	1.0029	1.0029	0.2507	4.32	0.002
CULTIVAR*CONCENTRATION	3	5.5066	5.5066	1.8355	31.63	0.000
TREATMENT*CONCENTRATION	12	8.1641	8.1641	0.6803	11.72	0.000
CULTIVAR*TREATMENT*CONCENTRATION	12	1.4015	1.4015	0.1168	2.01	0.025
Error	200	11.6068	11.6068	0.0580		
Total	239	176.7212				

A 3. Determination of the effect of the selected pre-sowing treatment on the emergence of wheat cultivars under salt stress

Table A.14.Three-way analysis of variance for G%.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	892.3	892.3	892.3	15.83	0.000
TREAT	1	2171.5	2171.5	2171.5	38.51	0.000
CONC	2	32325.5	32325.5	16162.7	286.66	0.000
CULTIVAR*TREAT	1	3.2	3.2	3.2	0.06	0.813
CULTIVAR*CONC	2	273.1	273.1	136.5	2.42	0.100
TREAT*CONC	2	744.3	744.3	372.1	6.60	0.003
CULTIVAR*TREAT*CONC	2	37.7	37.7	18.8	0.33	0.718
Error	48	2706.4	2706.4	56.4		
Total	59	39153.9				

Table A.15.Three-way analysis of variance for GR.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.002648	0.002648	0.002648	8.88	0.005
TREAT	1	0.015698	0.015698	0.015698	52.67	0.000
CONC	2	0.255527	0.255527	0.127764	428.65	0.000
CULTIVAR*TREAT	1	0.000015	0.000015	0.000015	0.05	0.826
CULTIVAR*CONC	2	0.002948	0.002948	0.001474	4.95	0.011
TREAT*CONC	2	0.002693	0.002693	0.001347	4.52	0.016
CULTIVAR*TREAT*CONC	2	0.002994	0.002994	0.001497	5.02	0.010
Error	48	0.014307	0.014307	0.000298		
Total	59	0.296830				

Table A.16.Three-way analysis of variance for MGT.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.19	0.19	0.19	0.01	0.915
TREAT	1	72.36	72.36	72.36	4.40	0.041
CONC	2	656.00	656.00	328.00	19.94	0.000
CULTIVAR*TREAT	1	2.94	2.94	2.94	0.18	0.674
CULTIVAR*CONC	2	0.48	0.48	0.24	0.01	0.985
TREAT*CONC	2	52.48	52.48	26.24	1.59	0.213
CULTIVAR*TREAT*CONC	2	1.54	1.54	0.77	0.05	0.954
Error	48	789.69	789.69	16.45		
Total	59	1575.68				

Table A.17.Three-way analysis of variance for shoot length.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	199.00	199.00	199.00	122.50	0.000
TREAT	1	752.39	752.39	752.39	463.15	0.000
CONC	2	5015.33	5015.33	2507.66	1543.63	0.000
CULTIVAR*TREAT	1	33.65	33.65	33.65	20.71	0.000
CULTIVAR*CONC	2	33.05	33.05	16.52	10.17	0.000
TREAT*CONC	2	106.59	106.59	53.29	32.81	0.000
CULTIVAR*TREAT*CONC	2	7.46	7.46	3.73	2.30	0.111
Error	48	77.98	77.98	1.62		
Total	59	6225.44				

Table A.18.Three-way analysis of variance for root length.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	80.50	80.50	80.50	46.78	0.000
TREAT	1	248.47	248.47	248.47	144.38	0.000
CONC	2	3800.45	3800.45	1900.22	1104.14	0.000
CULTIVAR*TREAT	1	2.52	2.52	2.52	1.47	0.232
CULTIVAR*CONC	2	4.51	4.51	2.26	1.31	0.279
TREAT*CONC	2	35.97	35.97	17.99	10.45	0.000
CULTIVAR*TREAT*CONC	2	7.11	7.11	3.56	2.07	0.138
Error	48	82.61	82.61	1.72		
Total	59	4262.15				

Table A.19.Three-way analysis of variance for shoot fresh weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	2.243	2.243	2.243	22.61	0.000
TREAT	1	12.603	12.603	12.603	127.06	0.000
CONC	2	107.703	107.703	53.851	542.89	0.000
CULTIVAR*TREAT	1	0.032	0.032	0.032	0.32	0.573
CULTIVAR*CONC	2	0.952	0.952	0.476	4.80	0.013
TREAT*CONC	2	1.316	1.316	0.658	6.63	0.003
CULTIVAR*TREAT*CONC	2	0.149	0.149	0.075	0.75	0.476
Error	48	4.761	4.761	0.099		
Total	59	129.760				

Table A.20.Three-way analysis of variance for root fresh weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	5.232	5.232	5.232	13.59	0.001
TREAT	1	45.701	45.701	45.701	118.75	0.000
CONC	2	221.432	221.432	110.716	287.69	0.000
CULTIVAR*TREAT	1	0.000	0.000	0.000	0.00	0.999
CULTIVAR*CONC	2	3.205	3.205	1.603	4.16	0.021
TREAT*CONC	2	12.345	12.345	6.172	16.04	0.000
CULTIVAR*TREAT*CONC	2	0.007	0.007	0.003	0.01	0.991
Error	48	18.473	18.473	0.385		
Total	59	306.394				

Table A.21.Three-way analysis of variance for shoot dry weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.74571	0.74571	0.74571	124.46	0.000
TREAT	1	0.52498	0.52498	0.52498	87.62	0.000
CONC	2	6.74316	6.74316	3.37158	562.73	0.000
CULTIVAR*TREAT	1	0.07716	0.07716	0.07716	12.88	0.001
CULTIVAR*CONC	2	0.32931	0.32931	0.16465	27.48	0.000
TREAT*CONC	2	0.03368	0.03368	0.01684	2.81	0.070
CULTIVAR*TREAT*CONC	2	0.00839	0.00839	0.00420	0.70	0.501
Error	48	0.28759	0.28759	0.00599		
Total	59	8.74998				

Table A.22.Three-way analysis of variance for root dry weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	1.6713	1.6713	1.6713	12.09	0.001
TREAT	1	9.2465	9.2465	9.2465	66.86	0.000
CONC	2	17.8992	17.8992	8.9496	64.71	0.000
CULTIVAR*TREAT	1	0.1170	0.1170	0.1170	0.85	0.362
CULTIVAR*CONC	2	0.2120	0.2120	0.1060	0.77	0.470
TREAT*CONC	2	3.6575	3.6575	1.8287	13.22	0.000
CULTIVAR*TREAT*CONC	2	0.0188	0.0188	0.0094	0.07	0.934
Error	48	6.6381	6.6381	0.1383		
Total	59	39.4605				

A4. The effect of the two composts on two wheat cultivars under non-saline and saline conditions

Table A.23.Three-way analysis of variance for E%.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	70.8	70.8	70.8	1.26	0.264
TREAT	6	11845.4	11845.4	1974.2	35.15	0.000
CONC	3	142602.1	142602.1	47534.0	846.25	0.000
CULTIVAR*TREAT	6	210.8	210.8	35.1	0.63	0.709
CULTIVAR*CONC	3	92.4	92.4	30.8	0.55	0.650
TREAT*CONC	18	9025.3	9025.3	501.4	8.93	0.000
CULTIVAR*TREAT*CONC	18	1629.9	1629.9	90.5	1.61	0.069
Error	112	6291.1	6291.1	56.2		
Total	167	171767.8				

Table A.24.Three-way analysis of variance for ER.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.000150	0.000150	0.000150	0.61	0.436
TREAT	6	0.087778	0.087778	0.014630	59.41	0.000
CONC	3	0.804449	0.804449	0.268150	1088.88	0.000
CULTIVAR*TREAT	6	0.001179	0.001179	0.000196	0.80	0.574
CULTIVAR*CONC	3	0.001543	0.001543	0.000514	2.09	0.106
TREAT*CONC	18	0.041130	0.041130	0.002285	9.28	0.000
CULTIVAR*TREAT*CONC	18	0.008000	0.008000	0.000444	1.80	0.033
Error	112	0.027581	0.027581	0.000246		
Total	167	0.971809				

Table A.25.Three-way analysis of variance for MET.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	3.703	3.703	3.703	0.55	0.462
TREAT	6	39.796	39.796	6.633	0.98	0.444
CONC	3	2558.405	2558.405	852.802	125.67	0.000
CULTIVAR*TREAT	6	56.736	56.736	9.456	1.39	0.223
CULTIVAR*CONC	3	13.530	13.530	4.510	0.66	0.576
TREAT*CONC	18	729.072	729.072	40.504	5.97	0.000
CULTIVAR*TREAT*CONC	18	131.951	131.951	7.331	1.08	0.381
Error	112	760.028	760.028	6.786		
Total	167	4293.220				

Table A.26.Three-way analysis of variance for shoot length.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	30.67	30.67	30.67	9.66	0.002
TREAT	6	1077.51	1077.51	179.59	56.57	0.000
CONC	3	12145.33	12145.33	4048.44	1275.37	0.000
CULTIVAR*TREAT	6	7.79	7.79	1.30	0.41	0.872
CULTIVAR*CONC	3	13.38	13.38	4.46	1.41	0.245
TREAT*CONC	18	718.59	718.59	39.92	12.58	0.000
CULTIVAR*TREAT*CONC	18	109.85	109.85	6.10	1.92	0.021
Error	112	355.52	355.52	3.17		
Total	167	14458.66				

Table A.27.Three-way analysis of variance for root length.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	58.39	58.39	58.39	21.49	0.000
TREAT	6	2031.05	2031.05	338.51	124.56	0.000
CONC	3	7293.66	7293.66	2431.22	894.61	0.000
CULTIVAR*TREAT	6	63.04	63.04	10.51	3.87	0.002
CULTIVAR*CONC	3	1.31	1.31	0.44	0.16	0.923
TREAT*CONC	18	538.77	538.77	29.93	11.01	0.000
CULTIVAR*TREAT*CONC	18	151.68	151.68	8.43	3.10	0.000
Error	112	304.37	304.37	2.72		
Total	167	10442.26				

Table A.28.Three-way analysis of variance for shoot fresh weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	2.010	2.010	2.010	6.07	0.015
TREAT	6	83.713	83.713	13.952	42.16	0.000
CONC	3	1129.836	1129.836	376.612	1138.14	0.000
CULTIVAR*TREAT	6	3.015	3.015	0.503	1.52	0.178
CULTIVAR*CONC	3	1.512	1.512	0.504	1.52	0.213
TREAT*CONC	18	111.271	111.271	6.182	18.68	0.000
CULTIVAR*TREAT*CONC	18	6.961	6.961	0.387	1.17	0.299
Error	112	37.061	37.061	0.331		
Total	167	1375.378				

Table A.29.Three-way analysis of variance for root fresh weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.3754	0.3754	0.3754	1.85	0.177
TREAT	6	31.2612	31.2612	5.2102	25.65	0.000
CONC	3	447.6521	447.6521	149.2174	734.58	0.000
CULTIVAR*TREAT	6	0.6014	0.6014	0.1002	0.49	0.812
CULTIVAR*CONC	3	0.1296	0.1296	0.0432	0.21	0.887
TREAT*CONC	18	42.1766	42.1766	2.3431	11.54	0.000
CULTIVAR*TREAT*CONC	18	3.2173	3.2173	0.1787	0.88	0.603
Error	112	22.7508	22.7508	0.2031		
Total	167	548.1644				

Table A.30.Three-way analysis of variance for shoot dry weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.09260	0.09260	0.09260	5.98	0.016
TREAT	6	2.23932	2.23932	0.37322	24.11	0.000
CONC	3	32.96672	32.96672	10.98891	709.78	0.000
CULTIVAR*TREAT	6	0.05823	0.05823	0.00971	0.63	0.708
CULTIVAR*CONC	3	0.09332	0.09332	0.03111	2.01	0.117
TREAT*CONC	18	2.30084	2.30084	0.12782	8.26	0.000
CULTIVAR*TREAT*CONC	18	0.09182	0.09182	0.00510	0.33	0.995
Error	112	1.73401	1.73401	0.01548		
Total	167	39.57687				

Table A.31.Three-way analysis of variance for root dry weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.00823	0.00823	0.00823	0.77	0.383
TREAT	6	0.71364	0.71364	0.11894	11.07	0.000
CONC	3	16.00156	16.00156	5.33385	496.48	0.000
CULTIVAR*TREAT	6	0.55729	0.55729	0.09288	8.65	0.000
CULTIVAR*CONC	3	0.00603	0.00603	0.00201	0.19	0.905
TREAT*CONC	18	1.64871	1.64871	0.09160	8.53	0.000
CULTIVAR*TREAT*CONC	18	0.48534	0.48534	0.02696	2.51	0.002
Error	112	1.20325	1.20325	0.01074		
Total	167	20.62405				

A.32. Extractable Nutrients Analysis for Cow Compost.

Association for Organics Recycling
Approved Laboratory

F.A.O CAMERON LEWIS
THE WOODHORN GROUP LTD
OVING
CHICHESTER
W SUSSEX
PO20 2BX

ANALYSIS REPORT ~ COMPOSTED MATERIAL

Customer information

Composting site	Tangmere
Grade (particle size range)	0-10mm
Grade Type	Additional
CA's Code	
Date sampled	21/06/2011
Batch age when sampled	17 weeks
Producer's sample code	Y8/11

Laboratory information

Received at lab	23-JUN-2011
Lab sample name	BCH Y8/11 0-10MM 17W
Lab sample number	34807
Report by	Dr R C Wilkinson
Report date	02-AUG-2011 04:33pm
Report number	38534

CAT-EXTRACTABLE NUTRIENTS [1,2]

	As received (fresh)		In dry matter		Method	Plant
Parameter	**Result**	**Units**	**Result**	**Units**	**Reference**	**significance**
NH4-N (ammonium-N)	137	mg/l	430	mg/kg	BS EN 13651	Primary nutrients
NO3-N (nitrate-N)	15.0	mg/l	47.3	mg/kg	BS EN 13651	
NH4-N plus NO3-N	152	mg/l	477	mg/kg	Calculated	
Phosphorus as P	98.5	mg/l	310	mg/kg	BS EN 13651	
Potassium as K	5266	mg/l	16591	mg/kg	BS EN 13651	
Magnesium as Mg	143	mg/l	452	mg/kg	BS EN 13651	Secondary nutrients
Sulphur as S	119	mg/l	374	mg/kg	BS EN 13651	
Boron as B	2.6	mg/l	8.2	mg/kg	BS EN 13651	Trace nutrients
Copper as Cu	0.9	mg/l	3.0	mg/kg	BS EN 13651	
Iron as Fe	31.1	mg/l	98.0	mg/kg	BS EN 13651	
Manganese a Mn	20.1	mg/l	63.4	mg/kg	BS EN 13651	
Molybdenum as Mo	N/D	mg/l	N/D	mg/kg	BS EN 13651	
Zinc as Zn	13.0	mg/l	41.0	mg/kg	BS EN 13651	
Sodium as Na	433	mg/l	1363	mg/kg	BS EN 13651	See footnote 3

1 See note i to table C.1 in Annex C of PAS100:2011, for information about CAT-extractable nutrient results.
2 Calcium and chloride are not determined as these are in the extractant and would affect corresponding results.
3 Together with chloride, influences nutrient uptake by plants and can inhibit this at high concentrations.
N/D = Not Determined, N/A = Not Applicable

Natural Resource Management Ltd, Coopers Bridge, Braziers Lane, Bracknell, Berkshire RG42 6NS
Tel +44 (0) 1344 886338 Fax + 44 (0) 1344 890972 E-Mail enquiries@nrm.uk.com Web www.nrm.uk.com
Registered in England No. 2577148. Registered office: Coopers Bridge, Braziers Lane, Bracknell, Berkshire RG42 6NS

A.33. Extractable Nutrients Analysis for Greenwaste Compost.

Association for Organics Recycling
Approved Laboratory

F.A.O CAMERON LEWIS
THE WOODHORN GROUP LTD
OVING
CHICHESTER
W SUSSEX
PO20 2BX

ANALYSIS REPORT ~ COMPOSTED MATERIAL

Customer information		Laboratory information	
Composting site	Tangmere Composting Facility	Received at lab	12-AUG-2013
Grade (particle size range)	0 to 25mm	Lab sample name	BATCH N6 0-25MM 17WK
Grade Type	Principal	Lab sample number	50519
CA's Code	TWG-TA-M0025	Report by	Andy Chase
Date sampled	08/08/13	Report date	11-SEP-2013 04:23pm
Batch age when sampled	17 Weeks	Report number	98306
Producer's sample code	N6		

CAT-EXTRACTABLE NUTRIENTS [1,2]

	As received (fresh)		In dry matter		Method	Plant
Parameter	**Result**	**Units**	**Result**	**Units**	**Reference**	**significance**
NH4-N (ammonium-N)	72.0	mg/l	202	mg/kg	BS EN 13651	Primary nutrients
NO3-N (nitrate-N)	<0.6	mg/l	<0.6	mg/kg	BS EN 13651	
NH4-N plus NO3-N	72.0	mg/l	202	mg/kg	Calculated	
Phosphorus as P	82.1	mg/l	230	mg/kg	BS EN 13651	
Potassium as K	2036	mg/l	5708	mg/kg	BS EN 13651	
Magnesium as Mg	197	mg/l	552	mg/kg	BS EN 13651	Secondary nutrients
Sulphur as S	77.6	mg/l	217	mg/kg	BS EN 13651	
Boron as B	2.2	mg/l	6.3	mg/kg	BS EN 13651	Trace nutrients
Copper as Cu	1.5	mg/l	4.3	mg/kg	BS EN 13651	
Iron as Fe	44.3	mg/l	124	mg/kg	BS EN 13651	
Manganese a Mn	23.6	mg/l	66.2	mg/kg	BS EN 13651	
Molybdenum as Mo	N/D	mg/l	N/D	mg/kg	BS EN 13651	
Zinc as Zn	16.1	mg/l	45.1	mg/kg	BS EN 13651	
Sodium as Na	277	mg/l	777	mg/kg	BS EN 13651	See footnote 3

1 See note i to table C.1 in Annex C of PAS100:2011, for information about CAT-extractable nutrient results.
2 Calcium and chloride are not determined as these are in the extractant and would affect corresponding results.
3 Together with chloride, influences nutrient uptake by plants and can inhibit this at high concentrations.
N/D = Not Determined, N/A = Not Applicable

Natural Resource Management Ltd, Coopers Bridge, Braziers Lane, Bracknell, Berkshire RG42 6NS
Tel +44 (0) 1344 886338 Fax + 44 (0) 1344 890972 E-Mail enquiries@nrm.uk.com Web www.nrm.uk.com
Registered in England No. 2577148. Registered office: Coopers Bridge, Braziers Lane, Bracknell, Berkshire RG42 6NS

A5. The Effect of the Combination of Priming and Compost on Seedling Emergence and Establishment of wheat cv. S-24 and cv. Slambo under Saline Conditions

Table A.34. Four-way analysis of variance for E%.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	189.6	189.6	189.6	6.47	0.012
Co	2	14210.0	14210.0	7105.0	242.31	0.000
P	1	9123.5	9123.5	9123.5	311.16	0.000
Con	3	128316.9	128316.9	42772.3	1458.74	0.000
Cu*Co	2	628.4	628.4	314.2	10.72	0.000
Cu*P	1	14.5	14.5	14.5	0.49	0.483
Cu*Con	3	37.0	37.0	12.3	0.42	0.739
Co*P	2	291.7	291.7	145.8	4.97	0.008
Co*Con	6	8303.3	8303.3	1383.9	47.20	0.000
P*Con	3	97.6	97.6	32.5	1.11	0.346
Cu*Co*P	2	18.8	18.8	9.4	0.32	0.727
Cu*Co*Con	6	177.6	177.6	29.6	1.01	0.420
Cu*P*Con	3	150.7	150.7	50.2	1.71	0.166
Co*P*Con	6	1713.6	1713.6	285.6	9.74	0.000
Cu*Co*P*Con	6	122.5	122.5	20.4	0.70	0.653
Error	192	5629.7	5629.7	29.3		
Total	239	169025.3				

Table A.35.Four-way analysis of variance for ER.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	0.004359	0.004359	0.004359	14.79	0.000
Co	2	0.199340	0.199340	0.099670	338.23	0.000
P	1	0.074123	0.074123	0.074123	251.54	0.000
Con	3	1.044961	1.044961	0.348320	1182.03	0.000
Cu*Co	2	0.009345	0.009345	0.004673	15.86	0.000
Cu*P	1	0.002269	0.002269	0.002269	7.70	0.006
Cu*Con	3	0.002073	0.002073	0.000691	2.34	0.074
Co*P	2	0.002487	0.002487	0.001243	4.22	0.016
Co*Con	6	0.022526	0.022526	0.003754	12.74	0.000
P*Con	3	0.002088	0.002088	0.000696	2.36	0.073
Cu*Co*P	2	0.001187	0.001187	0.000593	2.01	0.136
Cu*Co*Con	6	0.007414	0.007414	0.001236	4.19	0.001
Cu*P*Con	3	0.006542	0.006542	0.002181	7.40	0.000
Co*P*Con	6	0.039306	0.039306	0.006551	22.23	0.000
Cu*Co*P*Con	6	0.002600	0.002600	0.000433	1.47	0.190
Error	192	0.056579	0.056579	0.000295		
Total	239	1.477198				

Table A.36. Four-way analysis of variance for MET.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	6.373	6.373	6.373	10.73	0.001
Co	2	36.064	36.064	18.032	30.35	0.000
P	1	0.005	0.005	0.005	0.01	0.930
Con	3	1294.622	1294.622	431.541	726.38	0.000
Cu*Co	2	17.341	17.341	8.671	14.59	0.000
Cu*P	1	0.141	0.141	0.141	0.24	0.626
Cu*Con	3	13.012	13.012	4.337	7.30	0.000
Co*P	2	204.779	204.779	102.389	172.34	0.000
Co*Con	6	1628.191	1628.191	271.365	456.77	0.000
P*Con	3	364.123	364.123	121.374	204.30	0.000
Cu*Co*P	2	1.236	1.236	0.618	1.04	0.355
Cu*Co*Con	6	25.592	25.592	4.265	7.18	0.000
Cu*P*Con	3	2.974	2.974	0.991	1.67	0.175
Co*P*Con	6	485.411	485.411	80.902	136.18	0.000
Cu*Co*P*Con	6	7.926	7.926	1.321	2.22	0.043
Error	192	114.067	114.067	0.594		
Total	239	4201.855				

Table A.37. Four-way analysis of variance for shoot length.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	164.89	164.89	164.89	100.01	0.000
Co	2	2999.27	2999.27	1499.64	909.56	0.000
P	1	1418.20	1418.20	1418.20	860.16	0.000
Con	3	18262.45	18262.45	6087.48	3692.17	0.000
Cu*Co	2	58.65	58.65	29.32	17.79	0.000
Cu*P	1	10.16	10.16	10.16	6.16	0.014
Cu*Con	3	29.86	29.86	9.95	6.04	0.001
Co*P	2	69.92	69.92	34.96	21.20	0.000
Co*Con	6	574.00	574.00	95.67	58.02	0.000
P*Con	3	215.53	215.53	71.84	43.57	0.000
Cu*Co*P	2	21.87	21.87	10.93	6.63	0.002
Cu*Co*Con	6	27.44	27.44	4.57	2.77	0.013
Cu*P*Con	3	31.59	31.59	10.53	6.39	0.000
Co*P*Con	6	127.26	127.26	21.21	12.86	0.000
Cu*Co*P*Con	6	35.10	35.10	5.85	3.55	0.002
Error	192	316.56	316.56	1.65		
Total	239	24362.74				

Table A.38. Four-way analysis of variance for root length.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	300.83	300.83	300.83	157.37	0.000
Co	2	4997.06	4997.06	2498.53	1307.05	0.000
P	1	801.18	801.18	801.18	419.12	0.000
Con	3	9885.13	9885.13	3295.04	1723.72	0.000
Cu*Co	2	92.00	92.00	46.00	24.06	0.000
Cu*P	1	9.24	9.24	9.24	4.84	0.029
Cu*Con	3	43.03	43.03	14.34	7.50	0.000
Co*P	2	33.04	33.04	16.52	8.64	0.000
Co*Con	6	696.98	696.98	116.16	60.77	0.000
P*Con	3	45.10	45.10	15.03	7.86	0.000
Cu*Co*P	2	19.62	19.62	9.81	5.13	0.007
Cu*Co*Con	6	56.72	56.72	9.45	4.95	0.000
Cu*P*Con	3	2.42	2.42	0.81	0.42	0.738
Co*P*Con	6	86.31	86.31	14.39	7.53	0.000
Cu*Co*P*Con	6	12.65	12.65	2.11	1.10	0.362
Error	192	367.02	367.02	1.91		
Total	239	17448.33				

Table A.39. Four-way analysis of variance for shoot fresh weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	27.021	27.021	27.021	62.04	0.000
Co	2	415.407	415.407	207.704	476.87	0.000
P	1	242.541	242.541	242.541	556.85	0.000
Con	3	1632.102	1632.102	544.034	1249.06	0.000
Cu*Co	2	8.603	8.603	4.302	9.88	0.000
Cu*P	1	10.584	10.584	10.584	24.30	0.000
Cu*Con	3	10.322	10.322	3.441	7.90	0.000
Co*P	2	89.253	89.253	44.627	102.46	0.000
Co*Con	6	135.262	135.262	22.544	51.76	0.000
P*Con	3	97.814	97.814	32.605	74.86	0.000
Cu*Co*P	2	6.378	6.378	3.189	7.32	0.001
Cu*Co*Con	6	3.486	3.486	0.581	1.33	0.244
Cu*P*Con	3	3.669	3.669	1.223	2.81	0.041
Co*P*Con	6	43.466	43.466	7.244	16.63	0.000
Cu*Co*P*Con	6	4.742	4.742	0.790	1.81	0.098
Error	192	83.627	83.627	0.436		
Total	239	2814.278				

Table A.40. Four-way analysis of variance for root fresh weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	9.242	9.242	9.242	35.66	0.000
Co	2	103.973	103.973	51.986	200.58	0.000
P	1	87.030	87.030	87.030	335.80	0.000
Con	3	679.824	679.824	226.608	874.35	0.000
Cu*Co	2	0.171	0.171	0.086	0.33	0.719
Cu*P	1	0.408	0.408	0.408	1.57	0.211
Cu*Con	3	2.068	2.068	0.689	2.66	0.049
Co*P	2	2.640	2.640	1.320	5.09	0.007
Co*Con	6	23.657	23.657	3.943	15.21	0.000
P*Con	3	29.048	29.048	9.683	37.36	0.000
Cu*Co*P	2	4.005	4.005	2.003	7.73	0.001
Cu*Co*Con	6	10.849	10.849	1.808	6.98	0.000
Cu*P*Con	3	0.411	0.411	0.137	0.53	0.663
Co*P*Con	6	3.488	3.488	0.581	2.24	0.041
Cu*Co*P*Con	6	2.174	2.174	0.362	1.40	0.217
Error	192	49.762	49.762	0.259		
Total	239	1008.747				

Table A.41. Four-way analysis of variance for shoot dry weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	0.8946	0.8946	0.8946	89.46	0.000
Co	2	10.3955	10.3955	5.1977	519.73	0.000
P	1	3.3633	3.3633	3.3633	336.30	0.000
Con	3	46.1857	46.1857	15.3952	1539.40	0.000
Cu*Co	2	0.2252	0.2252	0.1126	11.26	0.000
Cu*P	1	0.4649	0.4649	0.4649	46.49	0.000
Cu*Con	3	0.2795	0.2795	0.0932	9.32	0.000
Co*P	2	0.7824	0.7824	0.3912	39.12	0.000
Co*Con	6	3.9053	3.9053	0.6509	65.08	0.000
P*Con	3	1.3733	1.3733	0.4578	45.77	0.000
Cu*Co*P	2	0.0977	0.0977	0.0488	4.88	0.009
Cu*Co*Con	6	0.4437	0.4437	0.0740	7.40	0.000
Cu*P*Con	3	0.1647	0.1647	0.0549	5.49	0.001
Co*P*Con	6	0.4437	0.4437	0.0740	7.39	0.000
Cu*Co*P*Con	6	0.1032	0.1032	0.0172	1.72	0.118
Error	192	1.9202	1.9202	0.0100		
Total	239	71.0429				

Table A.42. Four-way analysis of variance for root dry weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	4.7203	4.7203	4.7203	342.97	0.000
Co	2	6.8561	6.8561	3.4281	249.08	0.000
P	1	9.5704	9.5704	9.5704	695.38	0.000
Con	3	80.5911	80.5911	26.8637	1951.88	0.000
Cu*Co	2	0.0447	0.0447	0.0223	1.62	0.200
Cu*P	1	0.0736	0.0736	0.0736	5.35	0.022
Cu*Con	3	2.3198	2.3198	0.7733	56.18	0.000
Co*P	2	0.1455	0.1455	0.0728	5.29	0.006
Co*Con	6	3.0122	3.0122	0.5020	36.48	0.000
P*Con	3	5.5054	5.5054	1.8351	133.34	0.000
Cu*Co*P	2	0.0348	0.0348	0.0174	1.26	0.285
Cu*Co*Con	6	0.3640	0.3640	0.0607	4.41	0.000
Cu*P*Con	3	0.0324	0.0324	0.0108	0.79	0.503
Co*P*Con	6	0.0689	0.0689	0.0115	0.83	0.545
Cu*Co*P*Con	6	0.0301	0.0301	0.0050	0.36	0.901
Error	192	2.6425	2.6425	0.0138		
Total	239	116.0118				

Table A.43. Four-way analysis of variance for for seedling Na^+ content.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	27.0	27.0	27.0	0.45	0.501
Co	2	303.6	303.6	151.8	2.55	0.081
Pr	1	148.0	148.0	148.0	2.48	0.117
NaCl	3	50731.3	50731.3	16910.4	283.81	0.000
Cu*Co	2	32.4	32.4	16.2	0.27	0.762
Cu*Pr	1	2.2	2.2	2.2	0.04	0.848
Cu*NaCl	3	78.0	78.0	26.0	0.44	0.727
Co*Pr	2	1760.0	1760.0	880.0	14.77	0.000
Co*NaCl	6	18629.1	18629.1	3104.9	52.11	0.000
Pr*NaCl	3	2615.6	2615.6	871.9	14.63	0.000
Cu*Co*Pr	2	7.2	7.2	3.6	0.06	0.941
Cu*Co*NaCl	6	50.0	50.0	8.3	0.14	0.991
Cu*Pr*NaCl	3	4.9	4.9	1.6	0.03	0.994
Co*Pr*NaCl	6	4711.2	4711.2	785.2	13.18	0.000
Cu*Co*Pr*NaCl	6	7.7	7.7	1.3	0.02	1.000
Error	192	11440.2	11440.2	59.6		
Total	239	90548.6				

Table A.44. Four-way analysis of variance for for seedling Ca^{2+} content.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	38.558	38.558	38.558	91.98	0.000
Co	2	602.022	602.022	301.011	718.10	0.000
Pr	1	40.317	40.317	40.317	96.18	0.000
NaCl	3	614.388	614.388	204.796	488.57	0.000
Cu*Co	2	14.041	14.041	7.021	16.75	0.000
Cu*Pr	1	0.001	0.001	0.001	0.00	0.971
Cu*NaCl	3	2.618	2.618	0.873	2.08	0.104
Co*Pr	2	21.534	21.534	10.767	25.69	0.000
Co*NaCl	6	168.891	168.891	28.148	67.15	0.000
Pr*NaCl	3	6.304	6.304	2.101	5.01	0.002
Cu*Co*Pr	2	2.965	2.965	1.483	3.54	0.031
Cu*Co*NaCl	6	5.052	5.052	0.842	2.01	0.066
Cu*Pr*NaCl	3	4.536	4.536	1.512	3.61	0.014
Co*Pr*NaCl	6	7.858	7.858	1.310	3.12	0.006
Cu*Co*Pr*NaCl	6	7.150	7.150	1.192	2.84	0.011
Error	192	80.482	80.482	0.419		
Total	239	1616.717				

Table A.45. Four-way analysis of variance for for seedling K^{+} content.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	240.30	240.30	240.30	10.71	0.001
Co	2	11133.21	11133.21	5566.60	248.01	0.000
Pr	1	1052.80	1052.80	1052.80	46.91	0.000
NaCl	3	26289.88	26289.88	8763.29	390.44	0.000
Cu*Co	2	8.39	8.39	4.20	0.19	0.830
Cu*Pr	1	0.43	0.43	0.43	0.02	0.891
Cu*NaCl	3	21.59	21.59	7.20	0.32	0.810
Co*Pr	2	92.77	92.77	46.39	2.07	0.129
Co*NaCl	6	191.89	191.89	31.98	1.42	0.207
Pr*NaCl	3	46.18	46.18	15.39	0.69	0.562
Cu*Co*Pr	2	2.05	2.05	1.02	0.05	0.955
Cu*Co*NaCl	6	90.50	90.50	15.08	0.67	0.672
Cu*Pr*NaCl	3	10.49	10.49	3.50	0.16	0.926
Co*Pr*NaCl	6	344.82	344.82	57.47	2.56	0.021
Cu*Co*Pr*NaCl	6	33.86	33.86	5.64	0.25	0.958
Error	192	4309.40	4309.40	22.44		
Total	239	43868.56				

Table A.46. Four-way analysis of variance for for seedling Mg^{2+} content.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	6.3290	6.3290	6.3290	93.83	0.000
Co	2	23.9026	23.9026	11.9513	177.19	0.000
Pr	1	3.9538	3.9538	3.9538	58.62	0.000
NaCl	3	66.2444	66.2444	22.0815	327.38	0.000
Cu*Co	2	0.7233	0.7233	0.3616	5.36	0.005
Cu*Pr	1	0.0980	0.0980	0.0980	1.45	0.229
Cu*NaCl	3	1.5359	1.5359	0.5120	7.59	0.000
Co*Pr	2	0.1471	0.1471	0.0736	1.09	0.338
Co*NaCl	6	0.4774	0.4774	0.0796	1.18	0.319
Pr*NaCl	3	0.1829	0.1829	0.0610	0.90	0.440
Cu*Co*Pr	2	0.0652	0.0652	0.0326	0.48	0.618
Cu*Co*NaCl	6	1.5162	1.5162	0.2527	3.75	0.002
Cu*Pr*NaCl	3	0.3129	0.3129	0.1043	1.55	0.204
Co*Pr*NaCl	6	0.9606	0.9606	0.1601	2.37	0.031
Cu*Co*Pr*NaCl	6	1.1650	1.1650	0.1942	2.88	0.010
Error	192	12.9502	12.9502	0.0674		
Total	239	120.5645				

Table A.47. Four-way analysis of variance for for seedling the Ca^{2+}:Na^{+} ratio.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	28.89	28.89	28.89	5.20	0.024
Co	2	468.29	468.29	234.15	42.11	0.000
Pr	1	141.88	141.88	141.88	25.52	0.000
NaCl	3	4783.68	4783.68	1594.56	286.76	0.000
Cu*Co	2	8.81	8.81	4.40	0.79	0.454
Cu*Pr	1	2.08	2.08	2.08	0.37	0.541
Cu*NaCl	3	65.77	65.77	21.92	3.94	0.009
Co*Pr	2	105.84	105.84	52.92	9.52	0.000
Co*NaCl	6	1101.01	1101.01	183.50	33.00	0.000
Pr*NaCl	3	360.08	360.08	120.03	21.59	0.000
Cu*Co*Pr	2	1.35	1.35	0.68	0.12	0.886
Cu*Co*NaCl	6	19.14	19.14	3.19	0.57	0.751
Cu*Pr*NaCl	3	3.26	3.26	1.09	0.20	0.899
Co*Pr*NaCl	6	262.74	262.74	43.79	7.88	0.000
Cu*Co*Pr*NaCl	6	1.89	1.89	0.32	0.06	0.999
Error	192	1067.62	1067.62	5.56		
Total	239	8422.34				

Table A.48. Four-way analysis of variance for for seedling the K^+:Na^+ ratio.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cu	1	625.5	625.5	625.5	3.08	0.081
Co	2	6333.3	6333.3	3166.6	15.58	0.000
Pr	1	3067.8	3067.8	3067.8	15.10	0.000
NaCl	3	136698.2	136698.2	45566.1	224.22	0.000
Cu*Co	2	117.6	117.6	58.8	0.29	0.749
Cu*Pr	1	11.9	11.9	11.9	0.06	0.809
Cu*NaCl	3	1536.7	1536.7	512.2	2.52	0.059
Co*Pr	2	1629.0	1629.0	814.5	4.01	0.020
Co*NaCl	6	14085.1	14085.1	2347.5	11.55	0.000
Pr*NaCl	3	7773.0	7773.0	2591.0	12.75	0.000
Cu*Co*Pr	2	221.4	221.4	110.7	0.54	0.581
Cu*Co*NaCl	6	360.6	360.6	60.1	0.30	0.938
Cu*Pr*NaCl	3	11.7	11.7	3.9	0.02	0.996
Co*Pr*NaCl	6	4000.4	4000.4	666.7	3.28	0.004
Cu*Co*Pr*NaCl	6	483.3	483.3	80.6	0.40	0.881
Error	192	39018.3	39018.3	203.2		
Total	239	215973.7				

A6. Determination of the key ion in compost that is responsible for the improvement in the growth of wheat cultivars under salt stress

Table A.49. Three-way analysis of variance for E%.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	2296.2	2296.2	2296.2	70.99	0.000
TREAT	8	5847.4	5847.4	730.9	22.60	0.000
CONC	3	86645.3	86645.3	28881.8	892.97	0.000
CULTIVAR*TREAT	8	393.8	393.8	49.2	1.52	0.149
CULTIVAR*CONC	3	813.5	813.5	271.2	8.38	0.000
TREAT*CONC	24	15006.8	15006.8	625.3	19.33	0.000
CULTIVAR*TREAT*CONC	24	2045.3	2045.3	85.2	2.63	0.000
Error	288	9314.9	9314.9	32.3		
Total	359	122363.1				

Table A.50. Three-way analysis of variance for ER.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.006797	0.006797	0.006797	41.82	0.000
TREAT	8	0.089256	0.089256	0.011157	68.64	0.000
CONC	3	0.424021	0.424021	0.141340	869.58	0.000
CULTIVAR*TREAT	8	0.007965	0.007965	0.000996	6.13	0.000
CULTIVAR*CONC	3	0.006110	0.006110	0.002037	12.53	0.000
TREAT*CONC	24	0.258619	0.258619	0.010776	66.30	0.000
CULTIVAR*TREAT*CONC	24	0.023668	0.023668	0.000986	6.07	0.000
Error	288	0.046811	0.046811	0.000163		
Total	359	0.863247				

Table A.51.Three-way analysis of variance for MET.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	33.26	33.26	33.26	5.19	0.023
TREAT	8	530.56	530.56	66.32	10.34	0.000
CONC	3	3794.82	3794.82	1264.94	197.28	0.000
CULTIVAR*TREAT	8	188.28	188.28	23.53	3.67	0.000
CULTIVAR*CONC	3	20.81	20.81	6.94	1.08	0.357
TREAT*CONC	24	3992.49	3992.49	166.35	25.94	0.000
CULTIVAR*TREAT*CONC	24	483.59	483.59	20.15	3.14	0.000
Error	288	1846.63	1846.63	6.41		
Total	359	10890.45				

Table A.52. Three-way analysis of variance for shoot length.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	179.15	179.15	179.15	223.17	0.000
TREAT	8	2058.97	2058.97	257.37	320.61	0.000
CONC	3	11319.55	11319.55	3773.18	4700.23	0.000
CULTIVAR*TREAT	8	84.45	84.45	10.56	13.15	0.000
CULTIVAR*CONC	3	114.32	114.32	38.11	47.47	0.000
TREAT*CONC	24	1124.28	1124.28	46.84	58.35	0.000
CULTIVAR*TREAT*CONC	24	89.78	89.78	3.74	4.66	0.000
Error	288	231.20	231.20	0.80		
Total	359	15201.69				

Table A.53.Three-way analysis of variance for root length.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	26.87	21.75	21.75	14.48	0.000
TREAT	8	913.48	952.51	119.06	79.28	0.000
CONC	3	3136.49	3155.72	1051.91	700.38	0.000
CULTIVAR*TREAT	8	24.34	23.86	2.98	1.99	0.048
CULTIVAR*CONC	3	52.97	48.01	16.00	10.66	0.000
TREAT*CONC	24	5050.86	5051.59	210.48	140.14	0.000
CULTIVAR*TREAT*CONC	24	69.25	69.25	2.89	1.92	0.007
Error	287	431.05	431.05	1.50		
Total	358	9705.31				

Table A.54. Three-way analysis of variance for shoot fresh weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	2.9646	2.9646	2.9646	52.53	0.000
TREAT	8	10.4475	10.4475	1.3059	23.14	0.000
CONC	3	270.3526	270.3526	90.1175	1596.71	0.000
CULTIVAR*TREAT	8	0.9256	0.9256	0.1157	2.05	0.041
CULTIVAR*CONC	3	3.7681	3.7681	1.2560	22.25	0.000
TREAT*CONC	24	210.5833	210.5833	8.7743	155.46	0.000
CULTIVAR*TREAT*CONC	24	3.5595	3.5595	0.1483	2.63	0.000
Error	288	16.2546	16.2546	0.0564		
Total	359	518.8559				

Table A.55.Three-way analysis of variance for root fresh weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	5.581	5.581	5.581	28.08	0.000
TREAT	8	37.047	37.047	4.631	23.30	0.000
CONC	3	383.860	383.860	127.953	643.91	0.000
CULTIVAR*TREAT	8	2.800	2.800	0.350	1.76	0.084
CULTIVAR*CONC	3	2.225	2.225	0.742	3.73	0.012
TREAT*CONC	24	344.945	344.945	14.373	72.33	0.000
CULTIVAR*TREAT*CONC	24	10.718	10.718	0.447	2.25	0.001
Error	288	57.229	57.229	0.199		
Total	359	844.405				

Table A.56.Three-way analysis of variance for shoot dry weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.29382	0.29382	0.29382	46.52	0.000
TREAT	8	0.39335	0.39335	0.04917	7.79	0.000
CONC	3	11.63105	11.63105	3.87702	613.89	0.000
CULTIVAR*TREAT	8	0.30953	0.30953	0.03869	6.13	0.000
CULTIVAR*CONC	3	0.28603	0.28603	0.09534	15.10	0.000
TREAT*CONC	24	11.50185	11.50185	0.47924	75.88	0.000
CULTIVAR*TREAT*CONC	24	0.19684	0.19684	0.00820	1.30	0.162
Error	288	1.81886	1.81886	0.00632		
Total	359	26.43132				

Table A.57. Three-way analysis of variance for root dry weight.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	0.97833	0.97833	0.97833	55.60	0.000
TREAT	8	9.16596	9.16596	1.14574	65.12	0.000
CONC	3	30.77822	30.77822	10.25941	583.07	0.000
CULTIVAR*TREAT	8	1.25578	1.25578	0.15697	8.92	0.000
CULTIVAR*CONC	3	0.36861	0.36861	0.12287	6.98	0.000
TREAT*CONC	24	3.31002	3.31002	0.13792	7.84	0.000
CULTIVAR*TREAT*CONC	24	0.85941	0.85941	0.03581	2.04	0.004
Error	288	5.06746	5.06746	0.01760		
Total	359	51.78379				

A7. The Effect of compost on water holding capacity

Table A.58. One-way analysis of variance for water holding capacity.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
compost	2	683.50	341.75	254.24	0.000	0.000
Error	12	16.13	1.34			
Total	14	699.63				

A8. The Effect of Priming on Seed Water Uptake

Table A.59. Three-way analysis of variance for root length.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	477.89	477.89	477.89	646.31	0.000
PRIMING	1	724.16	724.16	724.16	979.38	0.000
CONCENTRATION	3	1867.15	1867.15	622.38	841.73	0.000
CULTIVAR*PRIMING	1	4.55	4.55	4.55	6.16	0.016
CULTIVAR*CONCENTRATION	3	29.93	29.93	9.98	13.49	0.000
PRIMING*CONCENTRATION	3	15.61	15.61	5.20	7.04	0.000
CULTIVAR*PRIMING*CONCENTRATION	3	15.90	15.90	5.30	7.17	0.000
Error	64	47.32	47.32	0.74		
Total	79	3182.52				

A9: The Effect of Priming on Seed Ion Leachate

Table A.60. Two-way analysis of variance for seed ion leachate after 0.5 h.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	54.8	54.8	54.8	12.64	0.003
Treat	1	2974.4	2974.4	2974.4	686.52	0.000
Cultivar*Treat	1	37.3	37.3	37.3	8.60	0.010
Error	16	69.3	69.3	4.3		
Total	19	3135.7				

Table A.61. Two-way analysis of variance for seed ion leachate after 1 h.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	63.0	63.0	63.0	9.38	0.007
Treat	1	3524.5	3524.5	3524.5	524.81	0.000
Cultivar*Treat	1	3.1	3.1	3.1	0.46	0.505
Error	16	107.5	107.5	6.7		
Total	19	3698.1				

Table A.62. Two-way analysis of variance for seed ion leachate after 1.5 h.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	106.3	106.3	106.3	15.36	0.001
Treat	1	3561.8	3561.8	3561.8	514.75	0.000
Cultivar*Treat	1	8.1	8.1	8.1	1.17	0.296
Error	16	110.7	110.7	6.9		
Total	19	3786.8				

Table A.63. Two-way analysis of variance for seed ion leachate after 2 h.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	132.6	132.6	132.6	20.01	0.000
Treat	1	3917.2	3917.2	3917.2	591.21	0.000
Cultivar*Treat	1	27.6	27.6	27.6	4.17	0.058
Error	16	106.0	106.0	6.6		
Total	19	4183.4				

Table A.64. Two-way analysis of variance for seed ion leachate after 6 h.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	225.8	225.8	225.8	24.73	0.000
Treat	1	4936.1	4936.1	4936.1	540.67	0.000
Cultivar*Treat	1	75.3	75.3	75.3	8.24	0.011
Error	16	146.1	146.1	9.1		
Total	19	5383.2				

Table A.65. Two-way analysis of variance for seed ion leachate after 12 h.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treat	1	4801.9	4801.9	4801.9	290.58	0.000
Cultivar*Treat	1	208.0	208.0	208.0	12.59	0.003
Error	16	264.4	264.4	16.5		
Total	19	5777.3				

Table A.66. Two-way analysis of variance for seed ion leachate after 24 h.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	2490.9	2490.9	2490.9	52.43	0.000
Treat	1	5190.6	5190.6	5190.6	109.25	0.000
Cultivar*Treat	1	425.0	425.0	425.0	8.95	0.009
Error	16	760.2	760.2	47.5		
Total	19	8866.8				

A10: The Effect of Priming on Seed Ion Uptake

Table A.67. Three-way analysis of variance for Na^+ uptake.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	0.3807	0.3807	0.3807	64.46	0.000
Treatment	1	0.6754	0.6754	0.6754	114.34	0.000
salt Conc.	3	28.7210	28.7210	9.5737	1620.72	0.000
Cultivar*Treatment	1	0.0923	0.0923	0.0923	15.63	0.000
Cultivar*salt Conc.	3	0.2099	0.2099	0.0700	11.84	0.000
Treatment*salt Conc.	3	0.2689	0.2689	0.0896	15.18	0.000
Cultivar*Treatment*salt Conc.	3	0.1628	0.1628	0.0543	9.19	0.000
Error	64	0.3780	0.3780	0.0059		
Total	79	30.8891				

Table A.68. Three-way analysis of variance for Ca^{2+} uptake.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	0.148990	0.148990	0.148990	367.87	0.000
Treatment	1	0.162035	0.162035	0.162035	400.08	0.000
salt Conc.	3	0.335668	0.335668	0.111889	276.26	0.000
Cultivar*Treatment	1	0.003689	0.003689	0.003689	9.11	0.004
Cultivar*salt Conc.	3	0.014705	0.014705	0.004902	12.10	0.000
Treatment*salt Conc.	3	0.030097	0.030097	0.010032	24.77	0.000
Cultivar*Treatment*salt Conc.	3	0.015416	0.015416	0.005139	12.69	0.000
Error	64	0.025921	0.025921	0.000405		
Total	79	0.736521				

Table A.69. Three-way analysis of variance for K^{+} uptake.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	5.1209	5.1209	5.1209	218.19	0.000
Treatment	1	4.4023	4.4023	4.4023	187.57	0.000
salt Conc.	3	10.3451	10.3451	3.4484	146.93	0.000
Cultivar*Treatment	1	0.7317	0.7317	0.7317	31.18	0.000
Cultivar*salt Conc.	3	0.1654	0.1654	0.0551	2.35	0.081
Treatment*salt Conc.	3	0.2599	0.2599	0.0866	3.69	0.016
Cultivar*Treatment*salt Conc.	3	0.4037	0.4037	0.1346	5.73	0.002
Error	64	1.5021	1.5021	0.0235		
Total	79	22.9312				

Table A.70. Three-way analysis of variance for Mg^{2+} uptake.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	0.06990	0.06990	0.06990	6.83	0.011
Treatment	1	0.32766	0.32766	0.32766	32.03	0.000
salt Conc.	3	1.22147	1.22147	0.40716	39.81	0.000
Cultivar*Treatment	1	0.00005	0.00005	0.00005	0.01	0.943
Cultivar*salt Conc.	3	0.08784	0.08784	0.02928	2.86	0.044
Treatment*salt Conc.	3	0.13502	0.13502	0.04501	4.40	0.007
Cultivar*Treatment*salt Conc.	3	0.02521	0.02521	0.00840	0.82	0.487
Error	64	0.65460	0.65460	0.01023		
Total	79	2.52174				

Table A.71. Three-way analysis of variance for K^+: Na^+ ratio.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	21.60	21.60	21.60	40.66	0.000
Treatment	1	121.91	121.91	121.91	229.51	0.000
salt Conc.	3	3912.63	3912.63	1304.21	2455.33	0.000
Cultivar*Treatment	1	0.64	0.64	0.64	1.20	0.278
Cultivar*salt Conc.	3	1.56	1.56	0.52	0.98	0.408
Treatment*salt Conc.	3	108.60	108.60	36.20	68.15	0.000
Cultivar*Treatment*salt Conc.	3	7.53	7.53	2.51	4.72	0.005
Error	64	34.00	34.00	0.53		
Total	79	4208.46				

Table A.72. Three-way analysis of variance for Ca^{2+}: Na^+ ratio.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cultivar	1	0.3239	0.3239	0.3239	17.18	0.000
Treatment	1	4.9948	4.9948	4.9948	264.98	0.000
salt Conc.	3	83.0410	83.0410	27.6803	1468.46	0.000
Cultivar*Treatment	1	0.0023	0.0023	0.0023	0.12	0.726
Cultivar*salt Conc.	3	0.0237	0.0237	0.0079	0.42	0.740
Treatment*salt Conc.	3	7.7233	7.7233	2.5744	136.58	0.000
Cultivar*Treatment*salt Conc.	3	0.2811	0.2811	0.0937	4.97	0.004
Error	64	1.2064	1.2064	0.0188		
Total	79	97.5965				

A11: The Effect of Priming on the Seed Recovery

Table A.73. Three-way analysis of variance for germination recovery.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
CULTIVAR	1	2915.6	2915.6	2915.6	6.53	0.014
TREATMENT	1	1433.2	1433.2	1433.2	3.21	0.079
NaCl	2	21942.1	21942.1	10971.0	24.57	0.000
CULTIVAR*TREATMENT	1	20.3	20.3	20.3	0.05	0.832
CULTIVAR*NaCl	2	3654.8	3654.8	1827.4	4.09	0.023
TREATMENT*NaCl	2	64.2	64.2	32.1	0.07	0.931
CULTIVAR*TREATMENT*NaCl	2	794.1	794.1	397.1	0.89	0.418
Error	48	21430.7	21430.7	446.5		
Total	59	52255.0				