RESPONSE OF WHEAT (*Triticum aestivum* L.) AND BARLEY (*Hordeun vulgare* L.) TO SALINITY STRESS

by

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Date: December 2015

Abstract

Good quality water for agricultural use is rapidly becoming a luxury due to competition for this water among the municipal, industrial and agricultural sectors. This has often forced growers to use poor quality water for irrigation. Salinity is one of the main sources of poor water quality and high electrical conductivities (EC's) due to salinity may become a problem. The aim of this study was to compare the response of South African spring wheat and South African spring barley at germination, seedling growth, vegetative growth, reproductive growth and maturity stage to salinity stress caused by irrigation with saline water. This study was conducted in the laboratory and under controlled glasshouse conditions at the University of Stellenbosch in the Western Cape Province of South Africa.

Treatments in trial 1 (incubation trial) were made up of three wheat cultivars (SST 027, SST 056 and SST 087) and three barley cultivars (Nemesia, Erica and Hessekwa) exposed to five EC levels of NaCl solutions (4, 8, 12, 16 and 20 dS m^{-1}) and a control (0 dS m^{-1}) of distilled water, during the germination phase. In trial 2 (pot trial), wheat cultivar SST 027 and barley cultivar SVG 13 were also subjected to the above solutions, but plants were grown till the tillering stage. In trial 3 (pot trial) cultivars used in trial 2 were subjected to five nutrient solutions with EC levels of 1.6, 3, 6, 9 and 12 dS m^{-1} and allowed to grow till maturity (harvesting stage). Fully balanced nutrient solution with EC = 1.6 dS m^{-1} was used as a control and NaCl was added to the solutions to obtain the needed EC.

In trial 1, final germination percentage (FGP), salt tolerance (ST) and germination rate (GR) were measured at 7 days after incubation. The study showed that when the EC level was increased, FGP, ST and GR of all wheat and barley cultivars tested were decreased. However, significant reduction was only observed at high EC levels with regard to FGP and ST. Wheat cultivars recorded faster GR compared to barley cultivars and tended to be less sensitive to salinity in the germination stage. Cultivars from the same species did not show significant differences. In trial 2, shoot length (SL), root length (RL), shoot fresh weight (SFW), root fresh weight (RFW), shoot dry weight (SDW) and root dry weight (RDW) were measured at 35 days after planting (DAP). In general, the study showed that salinity had a significant (P0.05) effect on seedling growth of all measured parameters of both wheat and barley. Mean values for most growth parameters were higher for barley cultivar SVG 13 as compared to wheat cultivar SST 027. However, little evidence was found to show that barley is more salt tolerant than wheat at the seedling stage. In trial 3, selected growth parameters were measured at tillering (28 DAP), booting (54 DAP), flowering (71 DAP) and maturity stage (150 DAP).

The study showed that salinity had a significant (P0.05) effect on the vegetative growth, reproductive growth and grain yield of both wheat and barley. Although barley generally produced higher dry weights especially at the early growth stages no clear evidence was found that South African spring barley is more salt tolerant than South African spring wheat.

Uittreksel

Besproeiingswater met 'n goeie kwaliteit vir landboukundige gebruik word vinning baie skaars weens kompetisie, a.g.v menslike en industriële gebruik. Produsente word dus dikwels gedwing om water met 'n swak kwaliteit te gebruik vir besproeiing. 'n Hoë sout inhoud (brakwater) soos gemeet deur 'n hoë elektriese geleidingsvermoë (EC), mag dus 'n problem wees. Die doel van hierdie studie was om te bepaal hoe Suid Afrikaanse lente koring en gars gedurende ontkieming asook saailing-, vegetatiewe-, reproduktiewe- en rypwordingstadiums reageer teenoor soutstremming wat veroorsaak is deur besproeiing met brakwater. Die studie is uitgevoer in laboratoriums en onder gekontrolleerde glashuistoestande by die Universiteit van Stellenbosch in die Weskaap Provinsie van Suid Afrika.

Behandelings in die eerste proef (inkubasie studie) het bestaan uit drie koring kultivars (SST 027, SST 056 en SST 087) en drie gars kultivars (Nemesia, Erica en Hessekwa) wat tydens ontkieming benat is met vyf NaCl-oplossings met EC waardes van 4, 8, 12, 16 en 20 dS m^{-1} onderskeidelik, asook 'n kontrole met gedistilleerde water (0 dS m^{-1}). In die tweede proef is die koring kultivar, SST 027 en die gars kultivar SVG 13 in 'n potproef ook aan bogenoemde oplossings blootgestel maar toegelaat om tot die stoelstadium te ontwikkel. In die derde proef is genoemde twee kultivars besproei met vyf voedingsoplossings met EC-waardes van 1.6, 3, 6, 9 en 12 dS m^{-1} en toegelaat om tot oesstadium te ontwikkel. 'n Volledig gebalanseerde voedingsoplossing met EC = 1.6 dS m^{-1} is as kontrole gebruik en NaCl is by ander oplossings gevoeg om die verlangde EC te verkry.

In die eerste proef waar die finale ontkiemingspersentasie (FOP), sout toleransie (ST) en ontkiemingstempo (OT) na 7 dae gemeet is, is gevind dat FOP, ST en OT van al die koring en gars kultivars wat getoets is, met toenemende EC gedaal het. Statisties betekenisvolle afnames in FOP en ST is egter slegs by hoë EC waardes waargeneem. Koring kultivars het vinniger ontkiem as gars kultivars en was geneig om meer tolerant teenooor sout stremming te wees vergeleke met gars. Verskille tussen kultivars van dieselfde spesie was egter weglaatbaar klein. In die tweede proef waar plante toegelaat is om te groei tot die stoelstadium (35 dae na plant) is al die gemete planteienskappe (stingel- en wortellengte, asook vars en droë massas van stingels en wortels) van beide gars kultivar, SVG 13 en koring kultivar, SST 027, betekenisvol verlaag deur 'n toename in EC van die besproeiingswater. Hoewel gars ten opsigte van die meeste gemete eienskappe groter gemiddeldes as koring getoon het, is weinig bewys gevind wat daarop dui dat die getoetsde gars kultivar SVG 13 meer souttolerant is as die koring kultivar SST 027.

In die derde proef waar dieselfde koring en gars kultivars vanaf plant tot oestyd besproei is met genoemde voedingsoplossings en metings tydens stoelstadium (28 dae na plant), stamverlenging (54 dae na plant), blomstadium (71 dae na plant) en oesrypstadium (150 dae na plant) gedoen is, is alle gemete vegetatiewe-, reproduktiewe- en opbrengskomponente van beide spesies verlaag deur die soutstremming. Hoewel gars ook in hierdie proef veral gedurende vroeë groeistadiums groter droë massas as koring geproduseer het, is geen konkrete bewyse gevind wat daarop dui dat die getoetsde Suid Afrikaanse lente gars kultivar SVG 13 meer sout tolerant is as die koring kultivar SST 027.

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Dedications

This work is dedicated to my beloved family especially my son, Okan Omaatla Bagwasi who joined the family on the 30th July 2015.

Message to share: "Knowledge is the only instrument of production that is not subject to diminishing returns."

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List of Abbreviations

$CaSO_4$	calcium sulphate
DAP	days after planting
DM	dry matter
dS m^{-1}	decisiemens per metre
DW	dry weight
EC	electrical conductivity
FGP	final germination percentage
FW	fresh weight
GW	grain weight
LA	leaf area
Mg L^{-1}	milligrams per litre
$MgSO_4$	magnesium sulphate
mM	millimolar
NaCl	sodium chloride
$NaHCO_3$	sodium bicarbonate
RDW	root dry weight
RFW	root fresh weight
RL	root length
SDW	shoot dry weight
SFW	shoot fresh weight
SL	shoot length
ST	salt tolerance
TDS	total dissolved solids

CHAPTER 1

INTRODUCTION

Salinity is the concentration of dissolved salts in water or soil and is expressed in terms of concentration (mg L^{-1}) or electrical conductivity (dS m^{-1}). According to Grewal (2010) it is one of the major abiotic environmental stresses affecting agricultural productivity. Musyimi et al. (2007) reported that nearly 7 % of world's total land area is affected by salinity. Salinity affects many morphological, physiological and biochemical processes, including seed germination, plant growth and water and nutrient uptake (Willenborg et al. 2004) resulting in reduced yield and quality (Basalah 2010). However, plant species differ in their sensitivity or tolerance to salts (Torech and Thompson 1993).

The progress of saline stress is generally a three stage process. Firstly, high salt concentrations decrease the osmotic potential of soil solution creating water stress in plants (Dubey 1997, Carvajal et al. 1999). Secondly, they form the basis for severe ion toxicity; this is due to the fact that the sodium ion is not readily sequestered into vacuoles as we see in halophates (Greenway and Munns 1980, Wahome et al. 2001) and thirdly, the exchange of salts with mineral nutrition results in major and micro nutrient imbalances and deficiencies (Grattan and Grieve 1999). The consequence of this three stage process leads to plant death as a result of severe growth retardation and molecular damage. Therefore, to be successful, growers require an understanding on how plants respond to salinity. According to Shannon (1984) and Owens (2001), increasing salinity has increased the need to understand the effects of salinity on crops, and genetic improvement of salt tolerance has become an urgent need for the future of agriculture in arid and semi-arid regions. Apse and Blumwald (2002), as well as Zhu (2001), reported that a clear understanding of plant response to salinity and the complex mechanisms of salt stress tolerance will be required for breeding of salt tolerant crop varieties. Germination and seedling growth under saline environment are the screening criteria which are widely used to select the salt tolerance genotype (Ashraf et al. 1990, Khan et al. 1993).

Wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) both belong to the grass family Poaceae (Gramineae). Although the two are related, they are two very different types of grasses. Barley has a chromosome number of 2n = 14 (Ceccarelli and Grando 2006), while wheat has 2n = 42 (Belay 2006).Wheat is a major cereal crop in many parts of the world and globally is the second most produced food among the cereal crops after maize.

Barley is a highly adaptable cereal grain and is the fourth most important cereal crop in the world after maize, wheat and rice. In South Africa, wheat is the second most important grain crop following maize and most of this wheat is bread wheat. Barley is the second most important small grain in South Africa and it is mainly used for production of malt, used in the brewing of beer. Currently, wheat and barley imports have reached record highs in South Africa, as production decreases and consumption continues to increase. In order for South Africa to be self-sufficient or at least decrease import needs, production of these winter crops has to be increased. Increasing the production of these crops under irrigation is an option. However, in a semi-arid country such as South Africa good quality water for agricultural use is rapidly becoming a luxury. During the dryer time (winter months) of the year when these crops are grown water quality in irrigational areas is often not that good and high Electrical Conductivities (EC's) due to salinity may become a problem. Therefore, the aim of this study was to better understand the response of South African spring wheat and spring barley to salinity stress by investigating:

- Effect of salinity stress on the germination of wheat and barley.
- Effect of salinity stress on seedling growth of wheat and barley.
- Effect of salinity stress on vegetative and reproductive growth and grain yield of wheat and barley.

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CHAPTER 2

LITERATURE REVIEW

2.1 **Introduction**

Salinity can affect crop growth severely and as such, it is considered to be one of the main abiotic factors limiting agricultural productivity. According to Geilfus et al. (2010), as an estimate, up to 20 % of the world's arable land and up to 50 % irrigated land is adversely affected by salinity. Large areas of the earth in which high salinity is a natural part of the environment, include coastal salt marshes, inland deserts and near the shores of inland lakes, such as the Great Salt Lake and the Dead Sea (Hopkins and Huner 2004). In inland deserts, evaporation exceeds precipitation and there is little, if any, leaching and salts accumulate in the soil. On the other hand, shores of inland lakes experience high salinity because those lakes have no outlets and so, salts accumulate as water evaporates.

Salinity is known to cause ionic toxicity, osmotic stress, oxidative stress and nutritional imbalance in plants (Habib et al. 2010). According to Ashraf (2010), the physiological toxic effects of salinity include decreased germination and seedling growth, reduced leaf expansion which causes a reduction in the photosynthetic area and dry matter production. Ions such as sodium (Na^+), chloride (Cl^-), sulphate (SO_4^{2-}), magnesium (Mg^{2-}), calcium (Ca^{2+}) and potassium (K^+) are associated with salinity. However, Na^+ and Cl^- are the most important ions that causes salinity. Both ions are toxic to plants and sodium ions cause deterioration of the physical structure of the soil (Dudley 1994, Hasegawa et al. 2000).

There are two types of salinity namely; natural (primary salinity) and human-induced (secondary salinity). According to Podmore (2009), primary salinity is the "natural occurrence of salts in the landscape for example salt marshes and salt lakes"; while secondary salinity is the "salinization of soil, surface water or groundwater due to human activity such as urbanisation and agriculture (irrigated and dry land)". Primary salinity is caused by two natural processes, the weathering of parent materials containing soluble salts and the deposition of oceanic salt carried in wind and rain. On the other hand, the most common causes of secondary salinity are land clearing and the replacement of perennial vegetation with annual crops and irrigation schemes using salt-rich irrigation water or having insufficient drainage.

2.2 **Impact of salinity in agriculture**

Agriculture plays an important role in the entire life of a given economy. It is a key economic driver as well as a key to a healthy biosphere (Mulvany 2003).

However, agricultural productivity is affected by salinity. Flowers (2006) reported that "Salinity has been a threat to agriculture in some parts of the world for over 3000 years; in recent times, the threat has grown". Salinity is a problem in many irrigated, arid and semiarid regions, where precipitation is insufficient to leach salts from the root zone (Francois and Maas 1994). Salinization of agricultural lands has serious consequences because much of the land must ultimately be withdrawn from production (Hopkins and Huner 2004), hence a huge impact in agriculture.

As a result of an increase in population, there is competition for fresh water among the municipal, industrial and agricultural sectors in many regions. According to Tilman et al (2002), this has resulted to a decreased allocation of fresh water to agriculture. This problem is expected to continue and to intensify in arid and semiarid regions, as well as less developed countries that already have high population growth rates. For this reason, growers have been pressurized to irrigate with water of certain salt content, such as drainage water, treated sewage water and ground water (Table 2.1).

Table 2.1: Classification of saline waters

Water class	**EC (dS m^{-1})**	**TDS (g/l)**	**Type of water**
Non-saline	<0.7	<0.5	Drinking and Irrigation water
Slightly saline	0.7-2.0	0.5-1.5	Irrigation water
Moderately saline	2.0-10.0	1.5-7.0	Primary drainage water and groundwater
Highly saline	10.0-20.5	7.0-15.0	Secondary drainage water and groundwater
Very highly saline	20.5- 45.0	15.0-35.0	Very saline groundwater
Brine	>45.0	>35.0	Brine

Source: Rhoades et al. (1992)

2.3 **Salinity effects on plants**

Plants are divided into halophytes and non-halophytes (glycophytes) depending on their response to salinity. Halophytes grow in high salt soils, for example marsh grass (the most tolerant one will continue to grow at concentrations of NaCl in the 200 to 500 mM range), while glycophytes such as beans, rice and maize can tolerate very little salt and may suffer irreparable damage at concentration of NaCl less than 50 mM (Hopkins and Huner 2004).

Plants are affected by salinity in different ways such as osmotic effect, toxic effect and ionic imbalance (Lauchli and Epstein 1990, Munns 2005, Podmore 2009). Osmotic stress is due to the presence of ions mainly Na^+ and Cl^- in the soil which limits the availability of water to the plant. On the other hand, excess accumulation of these ions in leaves leads to ion toxicity.

Podmore (2009) stated that "an excess of some salts can cause an imbalance in the ideal ratio of salts in solution and reduce the ability of plants to take up nutrients. For example, relatively high levels of calcium can inhibit the uptake of iron ('lime induced chlorosis'), and high sodium can exclude potassium". The result of these effects lead to plant death due to severe growth retardation and molecular damage.

2.3.1 **Effects of salinity on seed germination**

Acquaah (2002) defines seed as, 'the propagational unit of flowering species and the economic part of grain crops'. Seed is one of the most important inputs in crop production. Seed germination is one of the most critical stages in plant life and the most vulnerable to environmental stresses (Catalan et al. 1994, Saritha et al. 2007). Salinity is one of the most important abiotic environmental stresses affecting seed germination. It affects germination in two ways; there may be enough salt in the medium to decrease the osmotic potential to such a point which retard or prevent the uptake of water necessary for mobilization of nutrients required for germination and the salt constituents or ions may be toxic to the embryo (Rahman et al. 2008).

Investigations showed that the increase in salinity not only decrease the germination but also delayed the germination initiation (Rahman et al. 2008, Hussain et al. 2013). This complements Akbarimoghaddam et al. (2011) who found that by increasing NaCl concentration, germination is delayed and decreased germination in bread wheat cultivars. Findings by Sholi (2012) also indicated that, an increase of salt concentrations delayed seed germination of tomato cultivars especially at the highest concentration (150 mM).

2.3.2 **Effects of salinity on plant growth and development**

Growth is an irreversible increase in size or volume, while development is defined as changes during the life history of an organism, for example tissues form a specific pattern. Development is controlled by mechanisms such as genes, hormones, environment and cellular changes. Growth stages include embryogenesis, vegetative and reproductive development. Salinity affects both vegetative and reproductive development (Lauchli and Grattan 2007) and often reduces shoot growth, particularly leaf area, more than root growth (Lauchli and Epstein 1990).

Most investigations indicate that with increased concentration of NaCl, both root and shoot lengths decreases. This was found in barley (Naseer et al. 2001, Yousofinia et al. 2012) and wheat (Rahman et al. 2008, Akbarimoghaddam et al. 2011).

In an experiment with four tomato cultivars, Sholi (2012), reported that growth parameters (such as fresh and dry weights) were reduced by the saline conditions. As the salt concentration was increased, plant growth was reduced. Naseer et al. (2001) also reported that under salt stress fresh and dry weights (root and shoot) of barley cultivars decreased significantly. This was also recorded in wheat (Akbarimoghaddam et al. 2011). Salinity does not only affect vegetative development but also reproductive development. According to Khatun et al. (1995), salinity delayed flowering, reduced the number of productive tillers, the number of fertile florets per panicle, the weight per grain and grain yield of rice.

2.4 **Salinity effects on water relations**

Salinity affects leaf water potential, leaf osmotic potential and leaf pressure potential of plants. As salinity increases, leaf water potential and leaf osmotic potential decreases whereas leaf pressure potential increases. This was reported by Romero-Aranda et al. (2001) on tomato, Morales et al (1998) on *Argyranthemum coronopifolium* plants, Hernandez et al. (1999) on pea plants and Meloni et al. (2001) on cotton. According to Chaudhuri and Choudhuri (1997), relative water content, water uptake, transpiration rate, water retention and water use efficiency decreased under short-term NaCl stress in jute species. The stomatal conductance decreases with increasing salinity (Aziz and Khan 2001, Gulzar et al. 2003). Lu et al (2002) reported that with increasing salt concentration, evaporation rate decreased significantly in halophyte *Suaeda salsa*.

2.5 **Salinity effects on soils**

In discussing the effects of salts in the soil, the difference between sodicity and salinity has to be considered, the former being the high concentrations of Na^+ and the latter being the high concentrations of total salts (Taiz and Zeiger 1991). According to Rowell (1988), salinity affects a large number of soil physical and chemical properties. However, both salinity and sodicity affect soil structure (Agassi et al. 1981). Salinity can affect soil physical properties by causing fine particles to bind together into aggregates (Flocculation). This process is beneficial in terms of soil aeration, root penetration and root growth. However, sodicity has the opposite effect of salinity on soils as it causes soil dispersion and clay platelet and aggregate swelling (Warrence et al. 2003). Soil dispersion reduces soil permeability (Kenneth 1990).

Podmore (2009) emphasized that organic matter is destabilized in highly saline soils leading to dark greasy patches and also on very salty sites a complete loss of groundcover often occur on the soil surface exposing it to erosion.

2.6 **Irrigation salinity**

All irrigation water contains dissolved mineral salts and trace elements. However, the concentration and composition of the dissolved salts vary depending on the source of the irrigation water. The most common salts normally found in irrigation waters are NaCl, $CaSO_4$, $MgSO_4$ and $NaHCO_3$ (Grattan 2002). Water with high salinity is toxic to plants and poses a salinity hazard. According to Podmore (2009), irrigation salinity occurs as a result of increased rates of leakage and groundwater recharge causing the water table to rise. Major cause of excess leakage are inefficient irrigation and drainage systems.

Furthermore, Podmore (2009) emphasized that the impacts of irrigation salinity include agricultural, environmental and social aspects. Agricultural impacts due to irrigation salinity include reduced agricultural production, farm income and productivity of agricultural land. On the other hand, environmental impacts from land and stream salinity include increased soil and wind erosion and decline of native vegetation and loss of habitat, while social impacts include reduced aesthetic value of landscape.

2.7 **Management of salinity**

Leaching and the use of crops tolerant to salinity are some of the strategies that can be used to manage salinization. Tyagi and Sharma (2000), emphasized that modifying the environment to suit the plant and modifying the plant to suit the environment are the two main approaches to improve and sustain productivity in a saline environment.

2.7.1 **Leaching**

Many saline soils are due to irrigating with water containing moderate to high levels of salts (Horneck et al 2007). Two processes that cause salt to accumulate in the root zone are the upward movement of a shallow saline-water table and salts left in the soil as a result of insufficient leaching (Grattan 2002). To control the former, drains must be installed in the field while for the latter, the soil must be adequately leached. Leaching is the basic management tool for controlling salinity. It is the process of applying more water to the field than can be held by the soil in the crop root zone to such an extent that excess water drains below the root system, carrying salt with it.

Although leaching will minimize the accumulation of salt, it will not entirely correct the problem until an alternative irrigation source is secured to mix with or replace the poor-quality water (Horneck et al 2007).

2.7.2 **Use of crops tolerant to salinity**

Salt stress can also be managed by biologically manipulating the plants. The effects of salinity on productivity can be reduced through identification of plant genotypes with tolerance to salt, and incorporation of desirable traits into economically useful crop plants (Shannon 1984). When good quality water and adequate drainage are not available, the only option instead of abandoning the field may be to select crops that are tolerant to saline soil conditions. Some crops are very sensitive to salinity, while others can tolerate much higher salt concentrations in the soil solution. However, this will depend on soil texture and moisture content as well as environmental conditions such as temperature (Horneck et al. 2007).

2.8 **Salt tolerance**

Salt tolerance is the protoplasmic component of resistance to salt stress (Larcher 2003) or the ability of plants to grow and complete their life cycle on a substrate that contains high concentration of soluble salt (Sacher and Staples 1984, Parida and Das 2005). Resistance to salt stress involves the degree to which the photoplasm can tolerate the ionic imbalance associated with salinity and the toxic and osmotic effects of increased ion concentrations. This depend on the plant species, tissue type and vigor (Larcher 2003).

Zhu (2007) and Hopkins and Huner (2004) have classified plants into glycophytes and halophytes depending on their reaction to salinity. Salt tolerant plants (halophytes) can tolerate high internal concentrations of salts and take up salt with water, while glycophytes (salt resistant plants) cannot tolerate salt internally and exist in saline environments by excluding salt at their roots (Podmore 2009). According to Popp (1995), halophytes have tolerance mechanisms that include combination of salt exclusion (from root and leaf), excretion (salt glands, bladder hairs and re-translocation), succulence, transport and compartmentalization and compatible solutes. Glycophytes are severely inhibited or even killed by 10 – 20 dS m^{-1} NaCl, while halophytes can survive salinity in excess of 30 dS m^{-1}. Some halophates such as *Atriplex vesicaria* can tolerate extremely high levels of salts. It can produce high yields in the presence of 70 dS m^{-1} NaCl (Zhu 2007). Most agricultural plants are glycophytes (Greenway and Munns 1980).

According to salinity ratings (level of salt tolerance) by Maas (1990) and Salt Tolerance Database of USDA – ARS (2013), wheat (*Triticum aestivum* L.), Barley (*Hordeum vulgare* L.), rice (*Oryza sativa* L.), maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.) are rated as moderately salt-tolerant, salt-tolerant, salt-sensitive, moderately salt-sensitive and moderately salt-tolerant respectively. Salt tolerance of crops may vary with their growth stage (Maas and Grieve 1994). According to Maas and Poss (1989a), most plants are tolerant during germination. However, salt stress delays this process even though there may be no difference in the percentage of germinated seeds from one treatment to another. Läuchli and Grattan (2007) reported that most of the literature indicates that plants are particularly susceptible to salinity during the seedling and early vegetative growth stage as compared to germination. This was found in corn (Maas et al. 1983), cowpea (Maas and Poss 1989b), Melon (Botia et al. 2005) and tomato (del Amor et al. 2001).

In general, cereal plants are the most sensitive to salinity during the vegetative and early reproductive stages, and less sensitive during flowering and during the grain filling stage (Mass and Poss 1989a). However, a difference in the salt tolerance among genotype may also occur at different growth stages. In a study to evaluate salt tolerance of wheat genotypes using multiple parameters, El-Hendawy et al. (2005) found that tiller number, leaf number and leaf area at the vegetative stage decreased with increasing salinity. However, investigators further reported that at the same stage, the relative salt tolerance indices for all the measured parameters (tiller number, leaf number, leaf area, total biomass, spike length, spikelet number, grain number, 1000-grain weight and grain yield) varied among genotypes.

Most of the research suggests that, after the salt-sensitive early-vegetative growth stage, most crops become progressively more tolerant as the plants grow older (Läuchli and Epstein 1990, Maas and Grattan 1999). This was found in wheat, sorghum and cowpea where investigators reported that these crops were most sensitive during vegetative and early reproductive stages, less sensitive during flowering and least sensitive during the seed filling stage (Maas and Poss 1989a, Maas et al. 1986, Maas and Poss 1989b).

2.9 **Conclusion**

Salinity is a serious threat to agriculture and the environment in many parts of the world particularly in arid and semi-arid regions where most of the developing and undeveloped countries happen to fall. The problem of salinity will become worse due to rapidly growing human population in many countries because more food needs to be grown to feed the people.

This can be accomplished by an increase in cultivated land and/or by an increase in crop productivity per area. However, the former has brought agriculture to marginal, salt-affected lands. The increasing concern over the limited water resources, which forces growers to use poor quality water for irrigation in arid and semi-arid environments, also aggravate the salinity problem. Although salinity ratings (level of salt tolerance) by Maas (1990) showed that wheat (*Triticum aestivum* L.), which is classified as moderately salt-tolerant, should be less productive than barley (*Hordeum vulgare* L.), which is classified as salt-tolerant, literature showed that genotypes (varieties) may differ and plant responses to salinity may differ at different growth stages. At present little is known about the responses of South African wheat and barley cultivars and research with the objective to determine the effect of salinity on South African spring wheat and spring barley cultivars is needed.

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CHAPTER 3

Effect of salinity on the germination of wheat and barley cultivars in incubation tests

Abstract

A laboratory experiment was conducted to study the effect(s) of salinity on seed germination of three South African spring wheat (*Triticum aestivum* L.) cultivars (SST 027, SST 056 and SST 087) and three spring barley (*Hordeum vulgare* L.) cultivars (Nemesia, Erica and Hessekwa). The experiment was conducted in petri dishes in a growth incubator at a constant temperature of 20°C for seven days. Seeds were exposed to five sodium chloride (NaCl) solutions with electrical conductivities (EC) of 4, 8, 12, 16 and 20 dS m^{-1} and were compared to those exposed to a solution having an EC of 0 dS m^{-1} (distilled water) which served as a control. The experiment design was a Complete Randomized Design (CRD). The study showed that salinity had an effect on seed germination of all wheat and barley cultivars. Although all cultivars showed a reduction in total germination percentage, with increasing salinity levels from EC 0 to EC 20 dS m^{-1}, differences were only significant (P0.05) at high EC levels (16 to 20 dS m^{-1}). Wheat cultivars outperformed barley cultivars at EC levels 0, 4, 8, 12 and 16 dS m^{-1}. The salt tolerance of all cultivars was reduced due to increasing EC levels, but wheat cultivars tended to be less sensitive to salinity at germination stage.

Key words: Wheat, salinity, barley, seed germination, growth incubator, cultivar

3.1 Introduction

A uniform germination and establishment of crops depend on the quality of seed planted and the conditions under which the seed was planted (Acquaah 2002). Seed germination refers to a complex physiological process triggered by imbibition of water after possible dormancy mechanisms, is overcome followed by the emergence of the plumule and radicle (Anbumalarmathi and Mehta 2013). This process is very important for early establishment of crops. However, it may be affected by high concentrations of salts (Rahman et al. 2000). Salinity is one of the most widespread environmental factors limiting crop production globally, particularly in arid and semi-arid climates (Geissler et al. 2010). According to Greenway and Munns (1980), sodium chloride (NaCl) is a major factor limiting crop production because it affects almost all plant functions. High levels of NaCl in the soil or irrigation water have an adverse effect on seed germination (Mayer and Mayber 1982).

This effect is caused by ion toxicity (Greenway and Munns1980, Hampson and Simpson 1990) and the decrease in osmotic pressure (Levitt 1980, Bliss et al. 1986) or both (Huang and Redmann 1995).According to Villagra (1997), salinity may also delay the germination of seed, causing a declined rate and reduced germination percentage. However, it has been reported that different plant species may show different responses under saline conditions (Mehmet et al 2006, Shahid et al 2011). Responses can be determined by measuring percentage germination and seedling growth under saline conditions. Because little is known with regard to the response of different South African wheat and barley cultivars, the objective of this study was to assess the impact of salt stress on germination and germination rate of South African spring wheat and spring barley cultivars exposed to increasing EC levels due to increasing concentrations of NaCl.

3.2 Materials and Methods

3.2.1 Seed

Seeds of wheat cultivars (SST 027, SST 056 and SST 087) were supplied by Kaap Agri in Porterville, while seeds of barley cultivars (Nemesia, Erica and Hessekwa) were supplied by South African Barley Breeding Institute located in Caledon. Before planting, seed viability was tested to ensure that all seeds have a high germination rate.

3.2.2 Preparation of sodium chloride solutions

Five NaCl solutions having electrical conductivity (EC) of 4, 8, 12, 16 and 20 dS m^{-1} were prepared by dissolving NaCl (Merck 582 23 00 FL) in distilled water and compared to a solution having an EC of 0 dS m^{-1} (distilled water), which served as control. The EC of each solution was measured using a digital conductivity meter (Hanna, HI – 9811, USA).

3.2.3 Experimental details

3.2.3.1 Treatments

Treatments were made up of six cultivars (three for wheat and three for barley) exposed to five EC levels of NaCl solution (4, 8, 12, 16 and 20 dS m^{-1}) and a control (distilled water: 0 dS m^{-1}). Total number of experimental units was 144, viz 72 for wheat cultivars and barley cultivars respectively.

3.2.3.2 Experimental site, layout and design

The experiment was conducted in the dark in a growth incubator at the Department of Agronomy at Stellenbosch University, Western Cape, South Africa at a constant temperature of 20 °C. The experiment was laid out as a Complete Randomized Design (CRD) with four replicates for each cultivar.

3.2.3.3 Growing medium, sowing and irrigation schedule

A total of 144 petri-dishes (9 cm diameter) were used in this experiment with 24 petri-dishes for each cultivar. Petri-dishes were lined with filter paper and twenty seeds were placed in each petri-dish. After planting, filter papers in petri-dishes were moistened with 5 ml of the relevant NaCl solution. Petri-dishes were placed in zip loop plastic bags to prevent evaporation of water, hence minimizing changes in concentration of solutions.

3.2.3.4 Measurements and analysis

Seeds were considered germinated with the emergence of radicle and those germinated were counted daily for a period of seven days and removed from the petri-dishes. Two parameters of germination, namely final germination percentage (FGP) and germination rate (GR), were determined. Salt tolerance (ST), that is, the tolerance to NaCl in relation to control treatment was also calculated. These parameters were calculated as follows:

$$FGP = Ni / N \times 100$$

Where Ni is the number of germinated seed till i^{th} day and N is the total number of seeds sown (El Naim et al. 2012).

$$GR = (n_1t_1) + (n_2t_2) + \ldots\ldots\ldots + (n_xt_x) / X^n$$

Where n_1 is the number of germinants at the first day of germination, t_1 is the days from start to first germination and X^n is the total number of seeds germinated (Rubio-Casal et al. 2003).

ST = (Germination in particular treatment after seven days / Germination in control) x 100 (Rahman et al. 2008)

3.2.4 Statistical analysis

The data were subjected to Analysis of Variance (ANOVA) using STATISTICA software version 12. The Bonferroni test's least significant difference (LSD) (P = 0.05) was used for separation of means.

3.3 Results

Cultivars differed significantly with regard to FGP and ST, while the EC level also has a significant effect on both parameters. Cultivar x EC level interactions were also found for FGP and ST (Table 3.1). For this reason, main effects (cultivar and EC level) will not be discussed for these parameters.

Table 3.1: Significance levels (Pr > F) of the final germination percentage (FGP) and salt tolerance (ST) of wheat and barley cultivars as affected by main effects (cultivars and EC level) and the interaction between main effects.

Source of variation	Final Germination Percentage (FGP)	Salt tolerance (ST)
	Pr>F	Pr>F
Cultivars	0.00	0.00
EC level	0.00	0.00
Cultivar x EC level	0.00	0.00

Significant at the 0.05 probability level. ^{ns} not significant

3.3.1 Final Germination Percentage

3.3.1.1 Effect of cultivar x EC level interactions on Final germination percentage of wheat and barley cultivars.

In general, the final germination percentage (FGP) was reduced with increasing EC levels in all wheat and barley cultivars from between 80 to 100% at EC = 0 dS m^{-1} to almost 0% at EC =20 dS m^{-1} (Figure 3.1). In the case of wheat cultivars, no significant differences were shown when EC level increased from 0 to 16 dS m^{-1} while in the case of barley cultivars, no significant differences were shown when EC level increased from 0 to 8 dS m^{-1}. In general barley cultivars showed a low percentage germination for EC level 0 to 16 dS m^{-1} when compared to wheat cultivars.

No significant differences were shown between wheat cultivars, but barley cultivars Nemesia and Erica tended to have a low value compared to barley cultivar Hessekwa, as well as, all wheat cultivars at all EC levels 0 to 16 dS m^{-1}. At EC = 8 to 16 dS m^{-1} barley cultivars Erica and Nemesia showed significant lower percentage germination compared to all wheat cultivars, while Erica differ significantly from Hessekwa at EC = 12 dS m^{-1}.

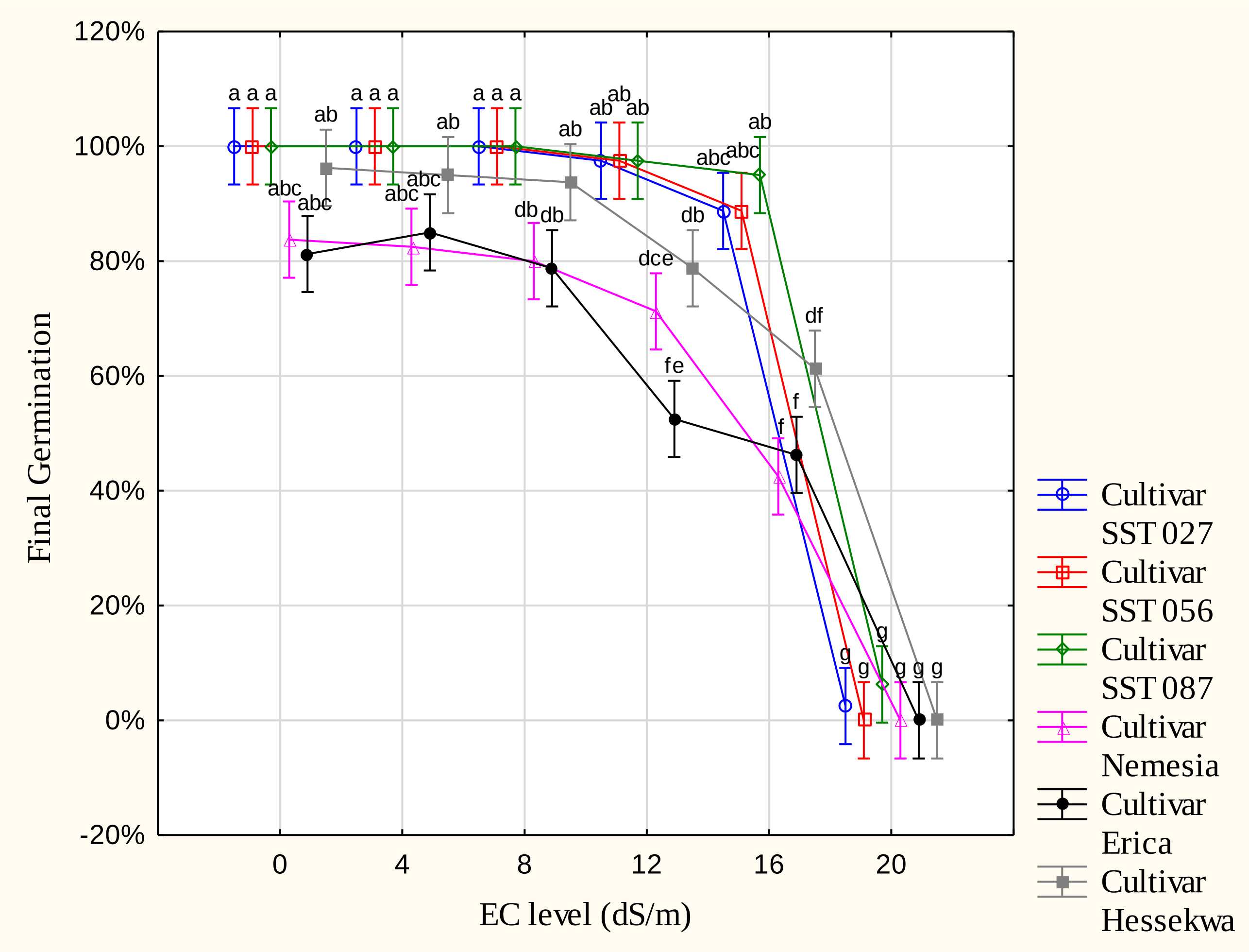

Figure 3.1: Final germination percentage (%) of wheat and barley cultivars as affected by EC level at 7 days after incubation.

3.3.2 Salt Tolerance

3.3.2.1 Effect of cultivar x EC level interactions on salt tolerance of wheat and barley cultivars.

The effect of cultivar x EC level interactions on salt tolerance (ST) of wheat and barley cultivars during germination after 7 days of incubation is shown in figure 3.2. Generally, salt tolerance decreased with increasing EC level from 0 to 20 dS m^{-1}, in all wheat and barley cultivars.

However, no significant differences were recorded when EC level increased from 0 to 8 dS m^{-1}. Furthermore, in the case of wheat cultivars, no significant differences were observed when EC level increased from 0 to 16 dS m^{-1}. In the case of barley cultivars, no significant differences were recorded when EC level increased from 0 to 8 dS m^{-1}. At EC = 12 dS m^{-1}, barley cultivar Erica showed a significant lower ST compared to Nemesia as well as all wheat cultivars tested. At EC = 12 dS m^{-1}, all barley cultivars tested showed lower ST values compared to wheat cultivars. No differences between cultivars or species (wheat and barley) were recorded at EC = 20 dS m^{-1}.

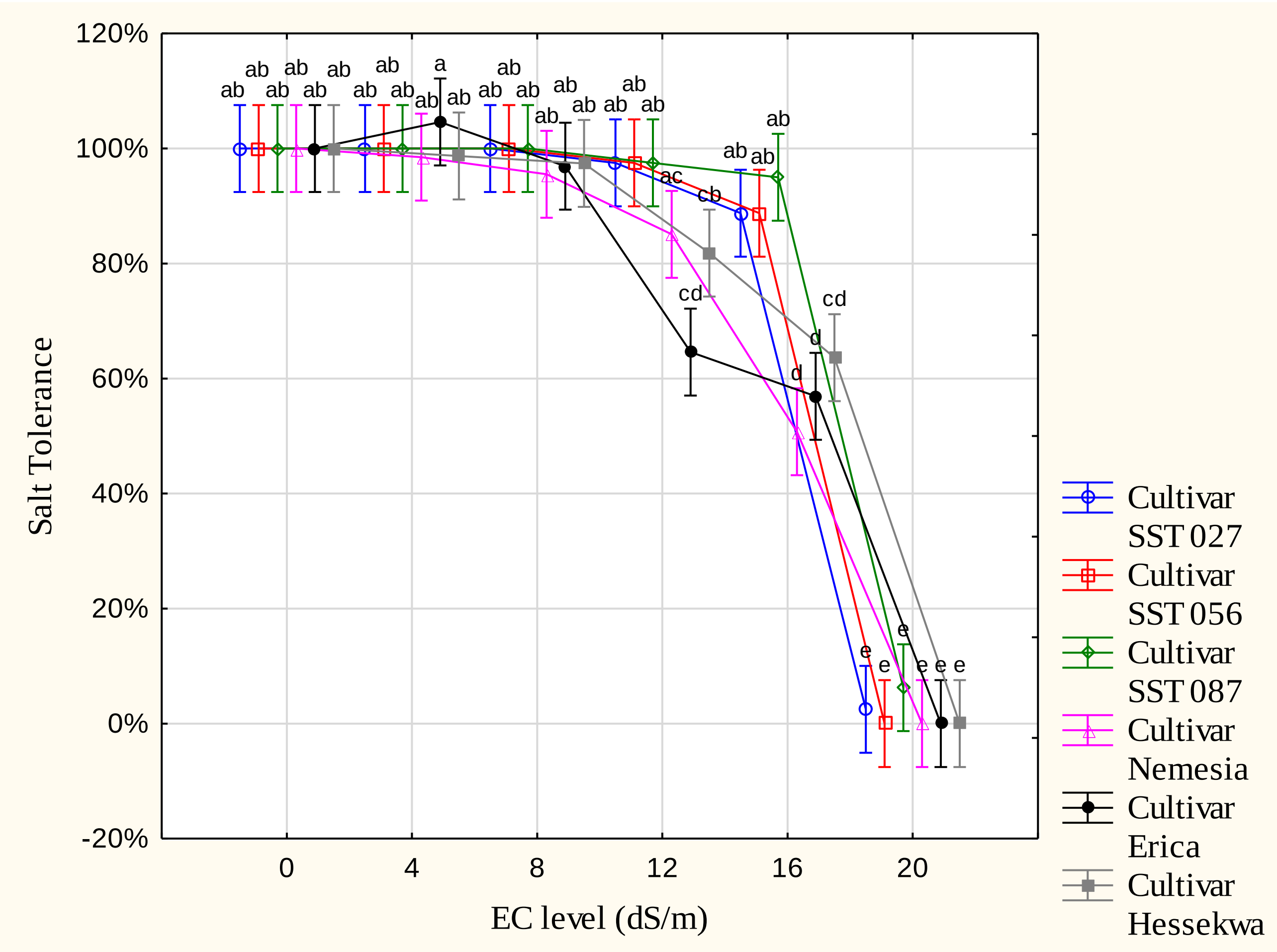

Figure 3.2: Salt tolerance (%) of wheat and barley cultivars as affected by EC level at 7 days after incubation.

3.3.3 Germination Rate

3.3.3.1 Effect of cultivar on seed germination rate

No cultivar x EC interaction was shown with regard to seed germination rate, but cultivars did differ (Table 3.2).

Wheat cultivars SST 027, SST 056 and SST 087 showed a faster rate (lower values) than barley cultivars Nemesia and Erica. However, no significant difference was shown between germination rate of wheat cultivar SST 027 and barley cultivar Hessekwa. In the case of both wheat and barley, no significant differences were recorded between cultivars of the same species.

Table 3.2: Effect of cultivar on seed germination rate after 7 days of incubation.

Cultivar	Germination rate (day)
SST 027	1.7^{cb}
SST 056	1.1^{c}
SST 087	1.6^{c}
Nemesia	3.3^{a}
Erica	3.6^{a}
Hessekwa	2.9^{ab}

Means within the column followed by the same letter are not significantly different at the 5 % probability level.

3.3.3.2 Effect of EC level on seed germination rate

The rate of germination (GR) decreased (higher values) when the EC level was raised from 0 to 20 dS m^{-1} (Table 3.3). As expected the fastest seed germination rate (lowest value) was observed in the control (0 dS m^{-1}) with mean value of 1.6 days while the slowest was recorded at the highest EC level (20 dS m^{-1}) with mean value of 7 days. No significant differences were observed on seed germination rate when EC level was increased from 0 to 12 dS m^{-1} and also from 12 to 16 dS m^{-1}, but the GR decreased significantly when EC was increased from 16 to 20 dS m^{-1}.

Table 3.3: Effect of EC level on seed germination rate after 7 days of incubation.

EC level	Germination rate (day)
0 dS m^{-1}	1.6^{c}
4 dS m^{-1}	1.7^{c}
8 dS m^{-1}	1.9^{c}
12 dS m^{-1}	2.3^{bc}
16 dS m^{-1}	3.2^{b}
20 dS m^{-1}	7.0^{a}

Means within the column followed by the same letter are not significantly different at the 5 % probability level.

3.4 Discussion

The FGP was calculated as the number of seeds germinated in percentage of the total number of seeds sown (Hussain et al. 2013). From the results obtained, it is evident that increasing salinity (EC level) decreased germination percentage of all the spring wheat and spring barley cultivars tested. This confirmed the findings of Yousofinia et al. (2012) and Naseer et al. (2001) who reported that germination percentage of barley cultivars decreased with increased concentration of salt, while Hussain et al. (2013) showed that an increase in salinity resulted in a decrease in the germination percentage of wheat cultivars. This reduced germination percentage due to increasing salinity has also been recorded in other crops such as cotton (Qadir and Shams 1997). The inability of seeds to germinate under saline conditions may be due to embryo damage by Na^{+}or Cl^{-} ions (Khajeh – Hosseini et al. 2003) or inhibition of seed water uptake (Mehmat et al. 2006, Saboora and Kiarostami 2006). Rahman et al. (2008) also emphasised that the reduction in germination percentage may be due to ion toxicity to the embryo or enough salt in the medium which decrease the osmotic potential to such a point to prevent the uptake of water required for mobilization of nutrient needed for germination.

Barley seemed to be less tolerant to salinity during the germination phase as FGP decreased significantly at EC levels of more than 8 dS m^{-1}, while in the case of wheat cultivars, significant decreases were only shown at EC level of more than 16 dS m^{-1}.

Barley cultivars, in contrast to wheat, also differed in their response to salinity during the germination phase with cultivar Hessekwa being more tolerant compared to Nemesia and especially Erica.

Salt tolerance is an index that reflects the response of a specific crop to increasing EC levels of the medium when compared to the control treatment (low EC). In the present study, salt tolerance decreased with increasing EC level in all cultivars. Wheat cultivars seemed to be more salt tolerant than barley cultivars at high EC levels (12 to 16 dS m^{-1}) during the germination stage. Similar results were reported by El Goumi et al. (2014) in a study which determined the effect of salt stress on germination and some physiological traits in barley cultivars and Rahman et al. (2008) in a study which determined the effect of NaCl salinity on wheat cultivars. No differences were shown between wheat cultivars while barley cultivar Nemesia seemed to be more salt tolerant than cultivar Erica at EC = 12 dS m^{-1}.

Germination rate is a measure of rapidity of germination, with lower values indicating faster germination (Osborne et al. 1993). The rate of germination for all cultivars decreased with increasing EC level and there were significant differences between seed germination rate of the spring wheat and spring barley cultivars tested, with wheat cultivars generally germinating more rapidly than barley cultivars. However, no differences were shown between cultivars of the same species (wheat and barley). This is in accordance with previous findings of Rubio – Casal et al. (2003) on two halophytic species and Datta et al. (2009) who reported a considerable reduction in the rate of germination of five varieties of wheat and Yousofinia et al. (2012) who stated that seed germination rate of barley cultivars decreased with increased concentrations of NaCl. This trend was also observed in rice cultivars (Anbumalarmathi and Mehta 2013). The reduction in the rate of germination at high salt levels might be due to the increase in osmotic potential which slow down the rate of water absorption and thus increase the time needed to take up enough water for germination to start (Heenan et al. 1988). Differences between wheat and barley may be attributed to the differences associated with the lemma and palea (glumes) of barley adhering to the grain during growth and ripening of the grain (Kirby and Appleyard 1984). This may reduce the rate of water absorbance.

3.5 Conclusion

In general, the study showed that salinity had an effect on seed germination of all South African spring wheat and barley cultivars tested. However, barley cultivars and especially Erica and Nemesia tend to be less tolerant during the germination phase than wheat cultivars tested at EC levels of 12 and 16 dS m^{-1}. The salt tolerance index of cultivars was reduced due to increasing EC levels, but wheat cultivars tended to be less sensitive to salinity at germination stage compared to barley cultivars. The seed germination rate of cultivars was also reduced due to increasing EC levels with generally higher rates for wheat than barley. No significant differences were however shown between cultivars of the same species.

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CHAPTER 4

Effect of salinity on seedling growth of wheat and barley grown in pot trials

Abstract

The effect of salinity on seedling growth of two winter cereal crops, namely wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) was evaluated using different salinity (EC) levels (0, 4, 8, 12, 16 and 20 dS m^{-1} NaCl). The experiment was conducted in pots in a temperature controlled (20/15°C day/night) glasshouse. The experiment design was a Complete Randomized Design (CRD), with four replicates. Shoot length (SL), root length (RL), shoot fresh weight (SFW), root fresh weight (RFW), shoot dry weight (SDW) and root dry weight (RDW) were measured at 35 days after planting. The study showed that salinity had a significant (P0.05) effect on seedling growth of all measured parameters of both wheat and barley. In general, very few differences were shown between wheat and barley with regard to their response to salinity during seedling stage, but barley tended to be slightly more salt tolerant than wheat at seedling stage when irrigated with saline water only after seedling emergence.

Key words: Wheat, salinity, barley, seedling growth, glasshouse

4.1 Introduction

Salinity is one of the major obstacles to increasing crop production worldwide especially in arid and semi-arid regions. Up to 20 % of the irrigated arable land in these regions is already affected by salt and is still expanding (Mühling and Läuchli 2003). Salinity in crop production will be exacerbated due to rapidly growing human population in many countries and the increasing concerns over the limited water resources which are forcing growers to use poor quality water for irrigation (Zeng et al. 2002).

Crop establishment comprises three processes namely germination, emergence and early seedling growth (Adjel et al. 2013). These early growth stages are the most sensitive to salinity stress (Cuartero et al. 2006, Muhammad and Hussain 2010, Adjel et al. 2013). Ashraf et al (2007) reported that these stages are critical factors to crop production under salt-stress conditions and important traits used to screen germplasm for salt tolerance to sustain food production under salt stress conditions. The objective of this study was to compare the effect of salt stress on the seedling growth of South African spring type wheat and barley exposed to increasing EC levels due to increasing concentrations of NaCl.

4.2 Materials and Methods

4.2.1 Experimental site

The study was conducted in pots in a temperature controlled (20/15 °C day/night) glasshouse at the Department of Agronomy at Stellenbosch University, Western Cape, South Africa. Each pot was filled with a mixture of sand and potting soil in the ratio 1:1 (w/w).

4.2.2 Treatments and experimental units

In this study two crops (wheat and barley) were subjected to five solutions with different sodium chloride concentrations (EC levels) and a control (distilled water). Because an earlier study indicated no significant differences between different cultivars of the same species for South African spring wheat and spring barley, only one cultivar was used per species. The study consists of two experiments (Trial A and Trial B). Pots were planted with five seeds of either South African spring wheat cultivar SST 027 or South African spring barley cultivar SVG 13 at a depth of 2.0 cm. Seed were provided by the Department of Agronomy, Stellenbosch University, Western Cape, South Africa and tested beforehand to ensure the germination rate of the seed. Seedlings were later thinned to three in each pot and allowed to grow until the beginning of tillering stage.

In Trial A, pots were saturated with the different solutions (EC levels) from planting onwards, while in Trial B, the pots were initially irrigated with municipality tap water until seedlings emerged. Thereafter, the pots were then irrigated with different NaCl solutions. The salinity treatments were made up of five NaCl solutions with EC levels of 4, 8, 12, 16 and 20 dS m^{-1} and the control (distilled water: 0 dS m^{-1}). The NaCl solutions were prepared by dissolving NaCl (Merck 582 23 00 FL) in distilled water. The electrical conductivity of each solution was measured using a digital conductivity meter (Hanna, HI – 9811). Irrigation was done twice a week and at each event, enough solution was applied to allow for a 10% drainage to prevent the accumulation of salt in the pots. Both trials (A and B) were running concurrently and all treatments were replicated four times. An experimental unit was made up by one pot and for this reason each trial consists of 48 pots.

4.2.3 Data recorded

On the 35th day after planting, seedlings were harvested to determine root and shoot lengths (cm), root and shoot fresh weights (g $seedling^{-1}$) and finally root and shoot dry mass (g $seedling^{-1}$). Shoot length was measured from the soil surface up to the highest point of the longest leaf.

Root length was measured from the crown down to the tip of the root. Dry mass was determined after the roots and shoots were dried in an oven at 80 °C for 48 hours in paper bags.

4.2.4 Statistical analysis

The experiment was laid out as a Complete Randomized Design (CRD). The data were subjected to Analysis of Variance (ANOVA) using STATISTICA software version 12. The Fisher's Least Significant Difference (LSD) test (P = 0.05) was used for separation of means.

4.3 Results

4.3.1 Trial A: Pots were irrigated with solutions with different EC levels from planting till harvesting at 35 days after planting (start of tillering stage).

Wheat and barley differed significantly with regard to root length (RL), shoot fresh weight (SFW) and root dry weight (RDW) (Table 4.1). The EC level had a significant effect on all growth parameters, while no significant crop x EC level interactions were found. For this reason, only main effects will be discussed.

Table 4.1: Significance levels (Pr>F) of selected growth parameters of wheat and barley as affected by main effects (crops and EC levels) and the interaction between main effects.

Source of Variation	Shoot Length (cm)	Root Length (cm)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)
Crop	0.49^{ns}	0.00	0.01	0.79^{ns}	0.06^{ns}	0.00
EC Level	0.00	0.00	0.00	0.00	0.00	0.00
Crop x EC Level	0.20^{ns}	0.78^{ns}	0.92^{ns}	0.60^{ns}	0.96^{ns}	0.52^{ns}

Significant at the 0.05 probability level. ^{ns} not significant

4.3.1.1 Effect of crop species on growth parameters

At 35 days after planting, mean shoot length (SL), shoot dry weight (SDW) and root fresh weight (RFW) did not differ significantly between the two crop species (Table 4.2). However, barley had the longest root length (RL), heaviest shoot fresh weight (SFW) and root dry weight (RDW) with mean values of 19.6 cm, 0.39 g seedling^{-1} and 0.04 g seedling^{-1} compared to wheat with values of 15.9 cm, 0.33 g seedling^{-1} and 0.03 g seedling^{-1}, respectively.

Table 4.2: Effect of crop species on selected growth parameters as measured at 35 days after planting.

Crop	Shoot Length (cm)	Root Length (cm)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)
Wheat	12.7[a]	15.9[b]	0.33[b]	0.05[a]	0.17[a]	0.03[b]
Barley	13.1[a]	19.6[a]	0.39[a]	0.05[a]	0.22[a]	0.04[a]

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

4.3.1.2 Effect of EC level on growth parameters of wheat and barley

Table 4.3: Effect of EC–level on selected growth parameters of winter cereals as measured at 35 days after planting

EC Level (dS m^{-1})	Shoot Length (cm)	Root Length (cm)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)
0	21.0[a]	35.5[a]	0.86[a]	0.11[a]	0.41[a]	0.06[a]
4	18.9[b]	29.9[b]	0.58[b]	0.08[b]	0.35[a]	0.06[a]
8	14.5[c]	17.3[c]	0.35[c]	0.06[c]	0.20[b]	0.04[b]
12	10.6[d]	10.9[d]	0.21[d]	0.04[d]	0.10[c]	0.02[c]
16	7.50[e]	7.75[de]	0.11[e]	0.02[e]	0.06[c]	0.02[c]
20	4.75[f]	5.38[e]	0.05[e]	0.01[e]	0.05[c]	0.02[c]

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

EC level had a significant effect on all selected growth parameters measured at 35 days after planting (Table 4.3).

Shoot length (SL) and root length (RL)

At 35 days after planting, SL (cm) showed significant decreases with all increases in EC levels tested (Table 4.3). The longest SL of 21.0 cm was recorded with EC level of 0 dS m^{-1} (control) while the shortest SL of 4.75 cm with EC level 20 dS m^{-1}. Although the RL was significantly reduced with increasing EC level, no significant differences were recorded between EC levels of 12 and 16 dS m^{-1} or between 16 and 20 dS m^{-1}. Control (0 dS m^{-1}) plants showed the longest RL of 35.5 cm while the shortest of 5.38 cm was recorded at the highest EC level of 20 dS m^{-1}.

Shoot fresh weight (SFW) and Shoot dry weight (SDW)

Although both parameters showed a decrease with an increase in EC levels from 0 to 20 dS m^{-1}, differences were significant only from 0 to 16 dS m^{-1}. Mean SFW and mean SDW varied with EC level from 0.86 g $seedling^{-1}$ (control) to 0.05 g $seedling^{-1}$ (20 dS m^{-1}) and from 0.11 g $seedling^{-1}$ (control) to 0.01 g $seedling^{-1}$ (20 dS m^{-1}) respectively (Table 4.3).

Root fresh weight (RFW) and Root dry weight (RDW)

Progressive decrease in RFW and RDW with increasing EC levels was also observed (Table 4.3). However, both parameters, did not show any significant difference when EC level increased from 0 to 4 dS m^{-1} and also no significant difference when EC level increased from 12 to 20 dS m^{-1}. Similarly to other parameters, the highest RFW and RDW values were recorded with 0 dS m^{-1} and the lowest with EC levels of 20 dS m^{-1}.

4.3.2 Trial B: Pots were initially watered with municipal water, and then watered with solutions with different EC levels after seedlings had emerged till harvesting at 35 days after planting (start of tillering stage).

Wheat and barley differed significantly with regard to shoot length (SL), shoot fresh weight (SFW), shoot dry weight (SDW), root fresh weight (RFW) and root dry weight (RDW) and the EC level had a significant effect on all growth parameters, significant crop x EC level interactions were found with regard to SL, SFW and RFW (Table 4.4). For this reason main effects (crop and EC levels) will not be discussed for these parameters.

Table 4.4: Significance levels (Pr>F) of selected growth parameters of wheat and barley as affected by main effects (crops and EC levels) and the interaction between main effects.

Source of Variation	Shoot Length (cm)	Root Length (cm)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)
Crop	0.01	0.55^{ns}	0.00	0.00	0.00	0.00
EC Level	0.00	0.00	0.00	0.00	0.00	0.00
Crop x EC Level	0.00	0.07^{ns}	0.00	0.38^{ns}	0.02	0.68^{ns}

Significant at the 0.05 probability level. ^{ns} not significant

4.3.2.1 Effect of crop species on growth parameters

At 35 DAP, mean root length (RL) did not differ significantly between the two crop species, wheat and barley (Table 4.5), while significant differences were observed with regard to shoot dry weight (SDW) and root dry weight (RDW). Barley had a higher SDW and RDW with mean values of 0.06 g seedling^{-1} and 0.05 g seedling^{-1} when compared to wheat with mean values of 0.05 g seedling^{-1} and 0.04 g seedling^{-1}, respectively.

Table 4.5: Effect of crop species on selected growth parameters as measured at 35 days after planting.

Crop	Shoot Length (cm)	Root Length (cm)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)
Wheat	12.5^{b}	22.7^{a}	0.25^{b}	0.05^{b}	0.15^{b}	0.04^{b}
Barley	13.3^{a}	22.1^{a}	0.41^{a}	0.06^{a}	0.24^{a}	0.05^{a}

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

4.3.2.2 Effect of EC level on growth parameters of wheat and barley

Table 4.6: Effect of EC–level on selected growth parameters of winter cereals as measured at 35 days after planting

EC Level (dS m^{-1})	Shoot Length (cm)	Root Length (cm)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)
0	18.6^{a}	32.9^{a}	0.76^{a}	0.10^{a}	0.41^{a}	0.06^{a}
4	16.5^{b}	27.1^{b}	0.51^{b}	0.08^{b}	0.33^{b}	0.06^{a}
8	12.3^{c}	22.8^{c}	0.28^{c}	0.05^{c}	0.17^{c}	0.04^{b}
12	11.0^{d}	18.8^{d}	0.20^{d}	0.04^{cd}	0.12^{d}	0.04^{bc}
16	10.3^{d}	16.6^{d}	0.14^{d}	0.03^{de}	0.09^{de}	0.03^{bc}
20	8.50^{e}	16.4^{d}	0.08^{e}	0.02^{e}	0.07^{e}	0.03^{c}

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

Root length (RL)

Although the RL showed a decrease with an increase in EC levels from 0 to 20 dS m^{-1}, differences were significant only from 0 to 8 dS m^{-1} and an increase in EC from 12 to 20 did not have any effect (Table 4.6). Mean RL varied with EC level from 32.9 cm (control) to 16.4 cm (20 dS m^{-1}).

Shoot dry weight (SDW)

Shoot dry weight showed a decrease with an increase in EC levels from 0 to 20 dS m^{-1} at 35 DAP (Table 4.6). However, no significant differences were recorded over the EC ranges of 8 and 12 dS m^{-1}, 12 and 16 dS m^{-1} or between 16 and 20 dS m^{-1}. Control (0 dS m^{-1}) plants showed the heaviest SDW of 0.10 g $seedling^{-1}$, while the lightest of 0.02 g $seedling^{-1}$ was recorded at the highest EC level of 20 dS m^{-1}.

Root dry weight (RDW)

Although RDW showed a decrease with an increase in EC levels from 0 to 20 dS m^{-1}, no significant differences were recorded when EC level increased from 0 to 4 dS m^{-1}, from 8 to

16 dS m^{-1} and from 12 to 20 dS m^{-1} (Table 4.6). Mean RDW varied with EC level from 0.06 g $seedling^{-1}$ (control) to 0.03 g $seedling^{-1}$ (20 dS m^{-1}).

4.3.2.3: Effect of crop x EC level interactions on selected growth parameters of wheat and barley.

Significant crop x EC level interactions were found with regard to shoot length (SL) and fresh weights of shoots (SFW) and roots (RFW) (Table 4.7).

Table 4.7: Effect of crop x EC level interactions on selected growth parameters of wheat and barley as measured at 35 days after planting.

Crop	EC level	Shoot Length (cm)	Shoot Fresh Weight (g)	Root Fresh Weight (g)
Wheat	0	17.0^{b}	0.59^{b}	0.32^{c}
	4	15.5^{c}	0.39^{c}	0.26^{c}
	8	12.8^{d}	0.24^{de}	0.16^{d}
	12	11.0^{ef}	0.13^{fg}	0.07^{ef}
	16	10.0^{f}	0.09^{g}	0.06^{f}
	20	8.50^{g}	0.07^{g}	0.05^{f}
Barley	0	20.3^{a}	0.94^{a}	0.49^{a}
	4	17.5^{b}	0.64^{b}	0.41^{b}
	8	11.8^{de}	0.32^{cd}	0.19^{d}
	12	11.0^{ef}	0.26^{de}	0.17^{d}
	16	10.5^{ef}	0.20^{ef}	0.13^{de}
	20	8.50^{g}	0.08^{g}	0.08^{ef}

Means within each column followed by the same letter are not significantly different at the 5 % probability level

Shoot length (SL)

Shoot lengths were significantly reduced with increasing EC level in both crop species (Table 4.7). Reduction ranged from 17.0 cm to 8.50 cm (50 %) in wheat and 20.3 cm to 8.50 cm (58 %) in barley. At EC levels of 0 and 4 dS m^{-1}, SL of barley (mean values of 20.3 and 17.5 cm) was significantly longer than that of wheat (mean value of 17.0 and 15.5 cm). However, no significant difference was observed at the higher EC levels (8-20 dS m^{-1}).

Shoot fresh weight (SFW)

Shoot fresh weights were significantly reduced as the level of EC was increased in both crop species (Table 4.7), but in the case of wheat no significant differences were recorded when EC level increased from 12 - 20 dS m^{-1}. At EC levels of 0, 4, 12 and 16 dS m^{-1}, SFW of barley seedlings was significantly heavier than that of wheat. At 20 dS m^{-1}, no significant difference was observed but barley recorded SFW of 0.08 g $seedling^{-1}$ as compared to 0.07 g $seedling^{-1}$ of wheat.

Root fresh weight (RFW)

Similar to SFW, RFW were also significantly reduced with increasing EC level in both crop species (Table 4.7), but with no significant effects in wheat when EC level increased from 12 to 20 dS m^{-1}. At EC level of 0, 4, 12 and 16 dS m^{-1}, RFW of barley seedlings was again significantly heavier than that of wheat. At 20 dS m^{-1}, no significant difference was observed but barley recorded a RFW of 0.08 g $seedling^{-1}$ compared to 0.05 g $seedling^{-1}$ of wheat.

4.4 Discussion

Two trials were conducted, differing only with regard to the quality of the water used for irrigation during the period from planting till emergence. Although trial B (where different EC treatments were applied after emergence only) showed some significant interactions with higher values for barley at low but not at high EC levels, trends (discussed below) for both trials were very similar. These significant higher values for barley at low EC levels of EC = 0 and EC = 4 suggested that South African spring barley might out yield South African spring wheat under these conditions, but SL, SFW and RFW of barley were reduced by 13%, 31.9% and 19.5% when EC was increased from 0 to 4 dS m^{-1} compared to 8.8%, 33.9% and 18.8% respectively in wheat. In support to the report by Maas (1990) and Salt Tolerance Database of USDA – ARS (2013), these results therefore generally showed little evidence of barley being more salt tolerant than wheat during the seedling stage when irrigated with saline water from planting, but appeared to be slightly more tolerant when irrigated with saline water after seedling emergence only.

Shoot length and root length are both important parameters for salt stress because roots are in direct contact with soil and absorbs water and nutrients from the soil, while shoots supply water and nutrients to the rest of the plant (Hussain et al. 2013). For these reasons, they both provide an important clue to the response of a plant to salt stress (Jamil and Rha 2004).

Shoot length was decreased with increasing EC level due to increasing concentration of sodium chloride (NaCl) in both trials. The reduction in shoot length may be due to extreme accumulation of salts in the cell wall, which modify the metabolic activities and limit the cell wall elasticity. In addition, secondary cell appears sooner and cell wall becomes rigid, and as a result the turgor pressure efficiency in cell enlargement decreases (Naseer et al. 2001, Taghipour and Salehi 2008). These processes may cause stunted shoots (Aslam et al. 1993). The results of the current study concur with the findings from previous studies (Rahman et al. 2008, Taghipour and Salehi 2008, Datta et al. 2009, Naseer et al. 2001, Akbarimoghaddam et al. 2011, Yousofinia et al. 2012 and Hussain et al. 2013).

Salinity caused a significant reduction in root length of both crop species in both trials. The reduction in root length may be due to toxic effects of the higher concentrations of NaCl as well as unbalanced nutrient uptake by the seedlings. Furthermore, high levels of salinity may have also inhibit the root elongation, thus slowing down the water uptake for overall osmotic adjustments of the plant body under high salt stress condition (Datta et al. 2009). Similar results were shown by previous studies (Rahman et al. 2008, Datta et al. 2009, Akbarimoghaddam et al. 2011 and Yousofinia et al. 2012).

Fresh weight of roots and shoots for both crop species significantly decreased with increasing level of EC in both trials. The reduction in shoot fresh weight could be due to shrinkage of cell contents, reduced development and differentiation of tissues, unbalanced nutrition, damage of membranes and disturbed avoidance mechanism (Kent and Lauchli 1985). On the other hand, the reduction in root fresh weight could be attributed to the toxic effects of salts and reduced nutrient to the growing roots (Qadir and Shams 1997). The reduction of fresh weight of both shoots and roots with increasing level of salt was previously reported (Taghipour and Salehi 2008, Naseer et al. (2001).

Dry weight of shoots and roots for both crop species decreased significantly with increasing salinity. These reductions in weights with increasing level of EC may be due to limited supply of metabolites to young growing tissues because metabolic production is significantly disturbed at high salinity, either due to the low water uptake or toxic effect of NaCl (Waisel 1972). This result is in accordance with previous findings (Naseer et al. 2001, Akbarimoghaddam et al. 2011).

4.5 Conclusion

This pot study conducted in the glasshouse showed that salinity reduced the seedling growth of both South African spring wheat and barley. Both shoot and root growth parameters were significantly reduced with increasing EC level in both crop species. Mean values for most growth parameters measured at 35 days after planting were higher for barley (cultivar SVG 13) than for wheat (cultivar SST 027). Barley showed superior shoot and root growth only at EC levels of 0 and 4 dS m^{-1} but not at higher EC levels (when good quality water (EC= 0) was used during the germination phase). In general it can therefore be concluded that little evidence was found to show that barley is more salt tolerant than wheat during the seedling stage when irrigated with saline water from planting, but barley tended to be slightly more tolerant than wheat when irrigated with saline water after emergence only.

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CHAPTER 5

Effect of salinity on the vegetative and reproductive growth and grain yield of wheat and barley grown in pot trials.

Abstract

A glasshouse experiment was conducted to study the effect(s) of salinity on the vegetative -, reproductive growth and grain yield of two cereal crops, South African spring wheat (*Triticum aestivum* L.) and South African spring barley (*Hordeum vulgare* L.). The experiment was conducted in pots in a temperature controlled (20/15 °C day/night) glasshouse. The experiment design was a Complete Randomized Block Design (CRBD) with four replicates. Crops were exposed to five nutrient solutions with electrical conductivities (EC) of 1.6, 3, 6, 9 and 12 dS m^{-1}. The lower EC level (1.6 dS m^{-1}) served as a control. The EC of the nutrient solution was adjusted by adding NaCl. Selected growth parameters were measured at tillering, booting (just when the flag leaf was visible), flowering and maturity stage. The study showed that salinity had a significant (P0.05) effect on the vegetative -, reproductive growth and grain yield of all measured parameters of both wheat and barley at various growth stages. Although barley generally produced higher dry weights at especially the early growth stages no clear evidence was found for South African spring barley to be more salt tolerant than South African spring wheat.

Key words: Salinity, vegetative growth, reproductive growth, grain yield, tillering stage, booting stage, flowering stage, wheat, barley, maturity stage.

5.1 Introduction

Crop plants are usually exposed to a multitude of natural biotic and abiotic stresses during their growth. These stresses limit their growth and productivity. Salinity is a major abiotic environmental stress that affects crop production and food security and adversely impact the social-economic fabric of many developing countries. According to Rogers et al (1995), salinity stress adversely affects almost all stages of growth and development and ultimately causing diminished economic yield and also quality of products. However, salt tolerance of crops may vary with their growth stage (Maas et.al 1994). Both vegetative and reproductive development have profound implications depending on whether the harvested organ is a stem, leaf, root, shoot, fruit, fibre or grain. Maas and Poss (1989) reported that in general, cereal plants are the most sensitive to salinity during the vegetative and early reproductive stages, and less sensitive during flowering and grain filling stages.

However, in an experiment with sorghum, Maas et al. (1986) found that sorghum was most sensitive during vegetative and early reproductive stages, less sensitive during flowering and least sensitive during the seed filling stage. Most of the research suggests that most crops become progressively more tolerant as the plants grow older (Läuchli and Epstein 1990, Maas and Grattan 1999). Little is however known with regard to the tolerance of South African spring wheat and barley cultivars to salinity. Therefore, the objectives of this study were to:

(a) Compare the effect of salt stress on the vegetative growth of South African spring wheat and barley exposed to increasing EC levels due to increasing concentrations of NaCl.
(b) Compare the effect of salt stress on the reproductive growth of South African spring wheat and barley exposed to increasing EC levels due to increasing concentrations of NaCl.
(c) Compare the effect of salt stress on the grain yield of South African spring wheat and barley exposed to increasing EC levels due to increasing concentrations of NaCl

5.2 Materials and Methods

5.2.1 Experimental site

The study was conducted in 2 litre pots in a temperature controlled (20/15 °C day/night) glasshouse at the Department of Agronomy at Stellenbosch University, Western Cape, South Africa. Each pot was filled with a mixture of sand and potting soil in the ratio 1:1 (± 2 cm below the brim). Four drainage holes were pinched in the bottom of each pot to ensure drainage hence preventing accumulation of salts in the growing medium and water stress. Pots were irrigated twice a week during the vegetative stage and three times per week during the reproductive stage to prevent water stress. During each irrigation event enough solution was applied to create 10 % drainage to prevent accumulation of salts in the pots.

5.2.2 Treatments and experimental units

In this study two crops, South African spring wheat and South African spring barley were subjected to five nutrient solutions with different sodium chloride concentrations (EC levels). Pots were planted with five seeds of either wheat cultivar SST 027 or barley cultivar SVG 13 at a depth of 2.0 cm. Seed were provided by the Department of Agronomy, Stellenbosch University, Western Cape, South Africa and tested beforehand to ensure the germination power of the seed. Only one cultivar was used per species because earlier research showed very few differences between cultivars of the same crop species. Seedlings were later thinned to three in each pot and allowed to grow until the maturity stage.

The salinity treatments were made up by five nutrient solutions with EC levels of 1.6, 3, 6, 9 and 12 dS m^{-1}. Fully balanced nutrient solution with EC = 1.6 dS m^{-1} was used as a control and NaCl was added to the other to obtain the needed EC. All treatments were replicated four times. An experimental unit was made up by one pot and for this reason the trial consists of 160 pots, viz 80 for wheat and barley respectively.

5.2.3 Data recorded

Measurements were done at tillering (vegetative), booting (reproductive), flowering (reproductive) and maturity stages.

First sampling

On the 28th day after planting, the first sampling was during the tillering stage. Plants were harvested to measure leaf area $plant^{-1}$ (using LI-3100 leaf area meter), root and shoot fresh weights (g $plant^{-1}$), root and shoot dry mass (g $plant^{-1}$) and finally number of tillers per plant. Dry mass was determined after the roots and shoots were dried in an oven at 80 °C for 48 hours in paper bags.

Second sampling

On the 54th day after planting, the second sampling was done at booting stage just when the flag leaf was visible. Plants were harvested to measure leaf area $plant^{-1}$ (using LI-3100 leaf area meter), root and shoot fresh weights (g $plant^{-1}$) and finally root and shoot dry mass (g $plant^{-1}$). Dry mass was determined after the roots and shoots were dried in an oven at 80 °C for 48 hours in paper bags.

Third sampling

On the 71st day after planting, the third sampling was done at the flowering stage. Plants were harvested to measure leaf area $plant^{-1}$ (using LI-3100 leaf area meter), root and shoot fresh weights (g $plant^{-1}$), root and shoot dry mass (g $plant^{-1}$), spike number $plant^{-1}$, fresh and dry matter (spike) and total number of tillers $plant^{-1}$. Dry mass was determined after the plant organs were dried in an oven at 80 °C for 48 hours in paper bags.

Fourth sampling

On the 150th day after planting, the fourth and final sampling was done at maturity stage. Plants were harvested to measure above ground plant dry matter (g $plant^{-1}$), root dry matter (g $plant^{-1}$), spike dry matter (g $plant^{-1}$), number of spikes/plant, number of grains/spike, number of grains/plant, grain weight/plant and 1000-grain weight (g). Dry mass was determined after the plant organs were dried in an oven at 80 °C for 48 hours in paper bags.

5.2.4 Statistical analysis

The experiment was laid out as a complete randomized block design (CRBD). The data were subjected to Analysis of Variance (ANOVA) using STATISTICA software version 12. The Bonferroni test's least significant difference (LSD) (P = 0.05) was used for separation of means. Graph was designed using MS-Excel 2013.

5.3 Results

5.3.1 First sampling (28 days after planting)

Wheat and barley differed significantly for all the growth parameters measured at 28 days after planting (Table 5.1). The EC level had no significant effect on fresh and dry weight of root. Moreover, no significant crop x EC level interaction was found for any of the parameters measured. For this reason, only main effects will be discussed.

Table 5.1: Significance levels (Pr>F) of selected growth parameters of wheat and barley as affected by main effects (crops and EC levels) and the interaction between main effects.

Source of Variation	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)	Number of tillers/plant	Leaf area (cm^2 $plant^{-1}$)
Crop	0.00	0.00	0.00	0.00	0.00	0.00
EC Level	0.00	0.00	0.37^{ns}	0.06^{ns}	0.02	0.01
Crop x EC Level	0.42^{ns}	0.64^{ns}	0.45^{ns}	0.47^{ns}	0.78^{ns}	0.21^{ns}

Significant at the 0.05 probability level. ^{ns} not significant

5.3.1.1 Effect of crop species on growth parameters

Crop had a significant effect on all selected growth parameters measured at 28 days after planting (Table 5.2).

Table 5.2: Effect of crop species on selected growth parameters as measured at 28 days after planting.

Crop	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)	Number of tillers/plant	Leaf area (cm^2 $plant^{-1}$)
Wheat	0.81^b	0.13^b	0.09^b	0.02^b	0.35^b	18.8^b
Barley	1.65^a	0.22^a	0.13^a	0.03^a	1.40^a	39.1^a

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

Shoot fresh weight (SFW) and shoot dry weight (SDW)

At 28 DAP, both mean SFW and mean SDW differed significantly between the two crop species (Table 5.2). Barley had a higher SFW and SDW with mean values of 1.65 g $plant^{-1}$ and 0.22 g $plant^{-1}$ when compared to wheat, with mean values of 0.81 g $plant^{-1}$ and 0.13 g $plant^{-1}$ respectively.

Root fresh weight (RFW) and root dry weight (RDW)

Similarly, significant differences were observed with regard to RFW and RDW between the two crop species at 28 days after planting (Table 5.2). Similar to SFW and SDW, barley recorded the highest RFW and RDW compared to wheat.

Number of tillers/plant

The mean number of tillers per plant differ significantly between wheat and barley at 28 days after planting. Wheat had a lower number of tillers per plant as compared to barley (Table 5.2).

Leaf area (LA)

At 28 days after planting, the mean LA (cm^2 $plant^{-1}$) differ significantly between the two crop species. Wheat recorded the lowest leaf area with mean value of 18.8 cm^2 $plant^{-1}$ when compared to barley with mean value of 39.1 cm^2 $plant^{-1}$.

5.3.1.2 Effect of EC level on selected growth parameters of wheat and barley

Table 5.3: Effect of EC–level on selected growth parameters of winter cereals as measured at 28 days after planting

EC Level (dS m^{-1})	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)	Number of tillers/plant	Leaf area (cm^2 $plant^{-1}$)
1.6	1.67^{a}	0.24^{a}	0.14^{a}	0.03^{a}	1.25^{a}	34.8^{a}
3	1.60^{a}	0.21^{a}	0.11^{a}	0.03^{a}	1.25^{a}	36.9^{a}
6	1.17^{ab}	0.17^{ab}	0.10^{a}	0.02^{a}	0.75^{ab}	28.4^{ab}
9	1.03^{ab}	0.15^{ab}	0.12^{a}	0.03^{a}	0.75^{ab}	27.3^{ab}
12	0.67^{b}	0.11^{b}	0.10^{a}	0.02^{a}	0.38^{b}	17.3^{b}

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

In general all parameters showed a decrease with an increase in EC levels from 1.6 (control) to 12 dS m^{-1}. EC level had a significant effect on SFW, SDW, number of tillers/plant and LA measured at 28 days after planting (Table 5.3). No significant effect was observed with regard to root fresh and dry weight.

Shoot fresh and dry weight

At 28 days after planting, both parameters showed a decrease with an increase in EC levels from 1.6 to 12 dS m^{-1}. However, both parameters did not show any significant difference when EC level increased from 1.6 to 9 dS m^{-1} and also no significant difference when EC level increased from 6 to 12 dS m^{-1}. The highest SFW and SDW values were recorded with 1.6 dS m^{-1} and the lowest with EC levels of 12 dS m^{-1}.

Number of tillers / plant

Although number of tillers per plant showed a decrease with an increase in EC levels from 1.6 to 12 dS m^{-1}, no significant differences were recorded when EC level increased from 1.6 to 9 dS m^{-1} and from 6 to 12 dS m^{-1} (Table 5.3). The highest mean number of tillers was recorded with the low EC levels (1.6 and 3 dS m^{-1}) while the lowest with high EC level (12 dS m^{-1}).

Leaf area

Leaf area showed a progressive decrease with increasing EC levels from 3 to 12 dS m^{-1}. However, no significant difference was observed when EC level increased from 1.6 to 9 dS m^{-1} and also from 6 to 12 dS m^{-1}. Mean leaf area varied with EC level from 36.9 cm^2 $plant^{-1}$ (3 dS m^{-1}) to 17.3 cm^2 $plant^{-1}$ (12 dS m^{-1}).

5.3.2 Second sampling (54 days after planting)

During the booting stage at 54 days after planting the two crop species differed significantly with regard to shoot fresh weight (SFW), shoot dry weight (SDW), root fresh weight (RFW) and root dry weight (RDW), but not for leaf area $plant^{-1}$. The EC level had a significant effect on all growth parameters while significant crop x EC level interaction was found with regard to RFW, RDW and leaf area (Table 5.4). For this reason, main effects (crop and EC level) will not be discussed for these parameters.

Table 5.4: Significance levels (Pr>F) of selected growth parameters of wheat and barley as affected by main effects (crops and EC levels) and the interaction between main effects.

Source of Variation	SFW (g $plant^{-1}$)	SDW (g $plant^{-1}$)	RFW (g $plant^{-1}$)	RDW (g $plant^{-1}$)	Leaf area (cm^2 $plant^{-1}$)
Crop	0.00	0.00	0.00	0.00	0.37^{ns}
EC Level	0.00	0.00	0.00	0.00	0.00
Crop x EC Level	0.22^{ns}	0.57^{ns}	0.00	0.03	0.01

Significant at the 0.05 probability level. ^{ns} not significant

SFW (shoot fresh weight).SDW (shoot dry weight). RFW (root fresh weight). RDW (root dry weight).

5.3.2.1 Effect of crop species on shoot fresh and shoot dry weight $plant^{-1}$

At 54 days after planting, barley had a higher SFW and SDW with mean values of 13.4 g $plant^{-1}$ and 2.22 g $plant^{-1}$ when compared to wheat with mean values of 8.12 g $plant^{-1}$ and 1.44 g $plant^{-1}$, respectively (Table 5.5).

Table 5.5: Effect of crop species on selected growth parameters as measured at 54 days after planting.

Crop	SFW (g plant^{-1})	SDW (g plant^{-1})	RFW (g plant^{-1})	RDW (g plant^{-1})	Leaf area (cm^2 plant^{-1})
Wheat	8.12^b	1.44^b	2.39^b	0.51^b	71.9^a
Barley	13.4^a	2.22^a	4.32^a	0.90^a	77.7^a

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

SFW (shoot fresh weight).SDW (shoot dry weight). RFW (root fresh weight). RDW (root dry weight).

5.3.2.2 Effect of EC level on shoot fresh and shoot dry weight plant^{-1}

Shoot fresh weight showed a decrease with an increase in EC levels from 1.6 to 12 dS m^{-1} at 54 days after planting (Table 5.6). However, differences were significant only from 1.6 to 6 dS m^{-1}. Mean SFW varied with EC level from 17.6 g plant^{-1} (control) to 4.87 g plant^{-1} (12 dS m^{-1}). Although shoot dry weight showed a decrease with an increase in EC levels from 1.6 to 12 dS m^{-1}, no significant differences were recorded when EC level increases from 3 to 6 dS m^{-1} and from 9 to 12 dS m^{-1}. Control (1.6 dS m^{-1}) plants showed the highest shoot dry weight (2.73 g plant^{-1}) while the lowest (0.96 g plant^{-1}) was recorded at the highest EC level of 12 dS m^{-1}.

Table 5.6: Effect of EC–level on shoot weights of wheat and barley as measured at 54 days after planting.

EC Level (dS m^{-1})	Shoot Fresh Weight (g plant^{-1})	Shoot Dry Weight (g plant^{-1})
1.6	17.6^a	2.73^a
3	13.6^b	2.21^b
6	11.1^c	2.03^b
9	6.70^d	1.24^c
12	4.87^d	0.96^c

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

5.3.2.3 Effect of crop x EC level interaction on selected growth parameters of wheat and barley

Significant crop x EC level interactions were found with regard to root fresh weight (RFW), root dry weight (RDW) and leaf area (LA) (Table 5.4).

Root fresh weight

Root fresh weights were significantly reduced as the level of EC was increased in both crop species (Table 5.7) In the case of wheat no significant differences were recorded when EC level increased from 3 to 12 dS m^{-1}, while no differences were recorded in barley when EC increased from 6 to 12 dS m^{-1}. At an EC level of 1.6 dS m^{-1}, mean RFW of barley (10.5 g $plant^{-1}$) was significantly higher than that of wheat (5.24 g $plant^{-1}$), while at EC levels 3 to12 dS m^{-1} no significant difference was observed. At EC level of 12 dS m^{-1} barley recorded root fresh weight of 0.87 g $plant^{-1}$ as compared to 0.34 g $plant^{-1}$ for wheat.

Root dry weight

Similar to root fresh weight, root dry weights were also significantly reduced with increasing EC level in both crop species (Table 5.7). Again, no significant effect was shown in wheat when EC level increased from 3 to 12 dS m^{-1} and in barley when EC level increased from 6 to 12 dS m^{-1}. At EC level of 1.6 and 3 dS m^{-1}, mean root dry weight of barley was significantly higher than that of wheat, but not at higher EC levels.

Leaf area

At 54 DAP, the mean leaf area was significantly reduced with increasing EC level in both crop species (Table 5.7). In the case of wheat, reduction ranged from 127.48 to 12.76 cm^2 $plant^{-1}$. In barley the reduction ranged from 138.00 to 49.20 cm^2 $plant^{-1}$. In wheat no significant reduction was shown when EC level increased from 1.6 to 6 dS m^{-1}, but in barley leaf area was significantly reduced when EC increased from 1.6 to 3 dS m^{-1}. However, no significant difference between leaf area of wheat and barley was recorded at any of the EC levels tested.

Table 5.7: Effect of crop x EC level interactions on selected growth parameters of wheat and barley as measured at 54 days after planting.

Crop	EC level (dS m^{-1})	Root Fresh Weight (g $plant^{-1}$)	Root Dry Weight (g $plant^{-1}$)	Leaf area (cm^2 $plant^{-1}$)
Wheat	1.6	5.24^{bc}	1.18^{bc}	127.48^{ab}
	3	3.46^{bd}	0.68^{cd}	92.82^{abc}
	6	2.02^{cd}	0.42^{d}	90.70^{abc}
	9	0.90^{d}	0.19^{d}	35.51^{de}
	12	0.34^{d}	0.09^{d}	12.76^{e}
Barley	1.6	10.5^{a}	1.97^{a}	138.00^{a}
	3	6.63^{b}	1.32^{b}	78.06^{bd}
	6	2.14^{cd}	0.61^{cd}	57.89^{cde}
	9	1.48^{d}	0.34^{d}	65.26^{cd}
	12	0.87^{d}	0.26^{d}	49.20^{cde}

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

5.3.3 Third sampling (71 days after planting)

Wheat and barley differed significantly with regard to SFW, SDW, RFW, RDW, leaf area, number of tillers $plant^{-1}$ and spike FW and the EC level had a significant effect on all growth parameters, significant crop x EC level interaction was found with regard to SFW, SDW, RFW, RDW, number of tillers $plant^{-1}$, number of spikes $plant^{-1}$, spike FW and spike DW at spike emergence at 71 days after planting (Table 5.8). For this reason, main effects will not be discussed for these parameters.

Table 5.8: Significance levels (Pr>F) of selected growth parameters of wheat and barley as affected by main effects (crops and EC levels) and the interaction between main effects.

SV	SFW (g)	SDW (g)	RFW (g)	RDW (g)	LA (cm^2 $plant^{-1}$)	No. of tillers	No. of spikes	Spike FW (g)	Spike DW (g)
Crop	0.00	0.00	0.00	0.00	0.00	0.00	0.14^{ns}	0.00	0.30^{ns}
EC level	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crop x EC level	0.00	0.01	0.00	0.00	0.12^{ns}	0.00	0.00	0.00	0.00

Significant at the 0.05 probability level. ^{ns} not significant.

SFW (shoot fresh weight).SDW (shoot dry weight). RFW (root fresh weight). RDW (root dry weight). LA (leaf area). FW (fresh weight).DW (dry weight). SV (source of variation)

5.3.3.1 Effect of crop species on growth parameters

As found during earlier samplings, barley generally showed higher values compared to wheat at 71days after planting with the exception of number of spikes and spike DW (Table 5.9). For example, barley produced a leaf area 127.55 cm^2 $plant^{-1}$ compared to 67. 51cm^2 $plant^{-1}$produced by wheat at 71 days after planting.

Table 5.9: Effect of crop species on selected growth parameters as measured at 71 days after planting.

Crop	SFW (g)	SDW (g)	RFW (g)	RDW (g)	LA (cm^2 $plant^{-1}$)	No. of tillers	No. of spikes	Spike FW (g)	Spike DW (g)
Wheat	11.93^b	2.96^b	2.00^b	0.59^b	67.51^b	2.80^b	2.30^a	3.73^a	1.01^a
Barley	24.12^a	5.05^a	6.22^a	1.26^a	127.55^a	7.45^a	2.60^a	2.74^b	0.91^a

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

SFW (shoot fresh weight). SDW (shoot dry weight). RFW (root fresh weight). RDW (root dry weight). LA (leaf area). FW (fresh weight). DW (dry weight).

5.3.3.2 Effect of EC level on leaf area of wheat and barley

As found during earlier samplings all parameters tested showed a decrease with an increase in EC level at 71 days after planting. The mean leaf area also showed a decrease with an increase in EC levels from 1.6 to 12 dS m^{-1}, but no significant differences were recorded between EC levels of 1.6 and 3 dS m^{-1}, 3 and 6 dS m^{-1}, 6 and 9 dS m^{-1} or 9 and 12 dS m^{-1} (Figure 5.1).

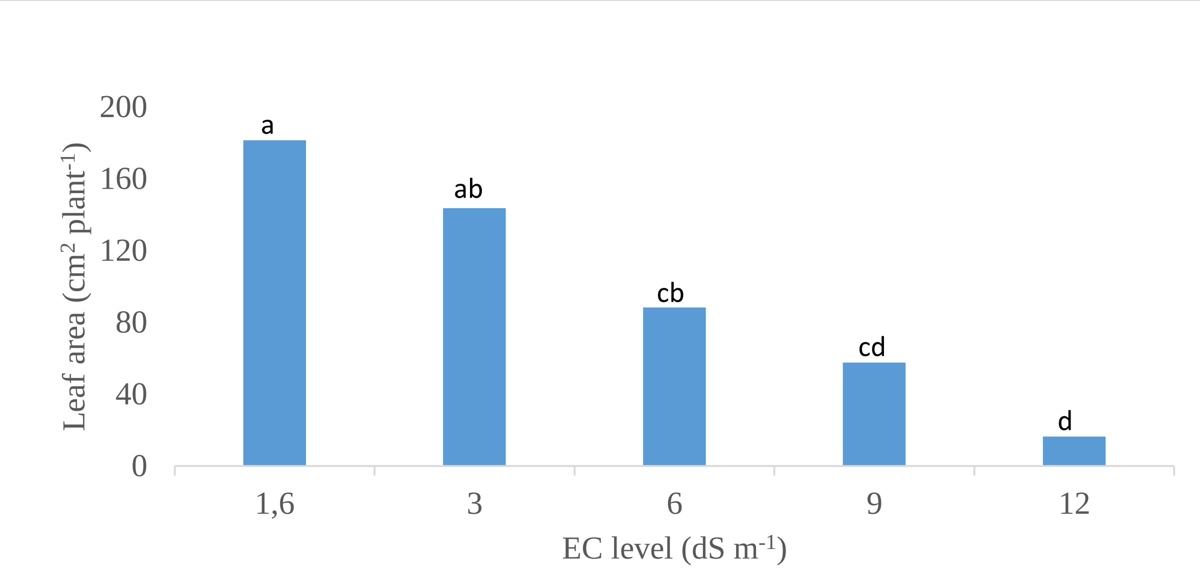

Figure 5.1: Leaf area of wheat and barley as affected by EC levels at 71 days after planting.

Bars with the same letter are not significantly different at p=0.05 probability level

5.3.3.3 Effect of crop x EC level interaction on selected growth parameters of wheat and barley.

At 71 days after planting, significant crop x EC level interactions were found with regard to shoot fresh and dry weight, root fresh and dry weight, number of tillers $plant^{-1}$, number of spikes $plant^{-1}$ and spike fresh and dry weight (Table 5.10).

Table 5.10: Effect of crop x EC level interactions on selected growth parameters of wheat and barley as measured at 71 days after planting.

Crop	EC level	SFW (g)	SDW (g)	RFW (g)	RDW (g)	No. of tillers	No. of spikes	Spike FW (g)	Spike DW (g)
Wheat	1.6	21.70[c]	4.91[b]	4.16[bc]	1.15[bc]	4.25[cde]	3.50[a]	6.48[a]	1.52[a]
	3	18.57[c]	4.55[b]	3.79[bcd]	0.93[cd]	4.25[cde]	3.00[ab]	5.65[ab]	1.42[ab]
	6	10.32[d]	2.79[c]	1.14[ce]	0.44[ef]	2.50[de]	2.00[ac]	3.01[cd]	0.91[ad]
	9	7.33[de]	2.03[cd]	0.69[de]	0.31[f]	2.00[de]	2.00[ac]	2.83[cd]	0.91[ad]
	12	1.76[e]	0.53[e]	0.20[e]	0.11[f]	1.00[e]	1.00[c]	0.69[e]	0.28[d]
Barley	1.6	43.22[a]	7.77[a]	19.48[a]	3.33[a]	13.25[a]	2.75[ab]	2.59[ce]	0.73[bd]
	3	31.44[b]	6.77[a]	6.68[b]	1.47[b]	9.25[b]	2.25[ac]	3.06[cd]	1.01[abc]
	6	22.52[c]	5.20[b]	2.57[ce]	0.77[cde]	6.50[bc]	3.00[ab]	3.69[cb]	1.28[ab]
	9	16.67[c]	4.10[b]	1.65[ce]	0.51[df]	5.00[cd]	3.25[ab]	3.27[c]	1.19[ab]
	12	6.74[de]	1.44[de]	0.73[de]	0.20[f]	3.25[cde]	1.75[bc]	1.08[de]	0.36[cd]

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

SFW (shoot fresh weight). SDW (shoot dry weight). RFW (root fresh weight). RDW (root dry weight). FW (fresh weight). DW (dry weight).

Shoot fresh and dry weight

Both shoot fresh and dry weights were significantly reduced with increasing EC level in both crop species (Table 5.10). In the case of shoot fresh weight, reduction ranged from 21.70 g plant^{-1} to 1.76 g plant^{-1} in wheat and 43.22 g plant^{-1} to 6.74 g plant^{-1} in barley. At EC levels of 1.6, 3, 6 and 9 dS m^{-1}, shoot fresh weights of barley were significantly higher than that of wheat while no significant difference was observed at EC level of 12 dS m^{-1}. However, barley still recorded the highest shoot fresh weight at this EC level with mean value of 6.74 g plant^{-1} compared to wheat with mean value of 1.76 g plant^{-1}. Regarding shoot dry weight, no significant differences were recorded when EC level increased from 1.6 to 3 dS m^{-1} and 6 to 9 dS m^{-1} in the case of barley.

Similar to shoot fresh weight, shoot dry weights of barley were significantly higher than that of wheat at EC levels of 1.6, 3, 6 and 9 dS m^{-1} while no significant difference was observed at EC level of 12 dS m^{-1}.

Root fresh and dry weight

In general barley produces higher root fresh and root dry weights than wheat at 71 days after planting (Table 5.10). Root fresh weights and root dry weights were significantly reduced with increasing EC level in both crop species, but with no significant difference between crops when EC level increased from 3 to 12 dS m^{-1} in the case of root fresh weight and from 6 to 12 dS m^{-1} in the case of root dry weight. In wheat, no significant differences were shown in root fresh weight when EC level increased from 1.6 to 6 dS m^{-1} and in root dry weight when EC increased from1.6 to 3 dS m^{-1}. In barley both root fresh and root dry weight decreased significantly when EC level increases of 1.6 and 3 dS m^{-1}.

Number of tillers plant^{-1}

The number of tillers plant^{-1} showed a decrease with an increase in EC levels from 1.6 to 12 dS m^{-1} in both crop species at the spike emerging stage 71 days after planting (Table 5.10). However, in the case of wheat, no significant differences were recorded when EC level increased from 1.6 to 12 dS m^{-1}, while in barley a significant decrease was already shown when EC decreases from 1.6, 3, and 6 dS m^{-1} . At EC levels of 1.6, 3, and 6 dS m^{-1}, number of tillers plant^{-1} of barley were significantly higher than that of wheat while no significant difference was observed at EC level of 9 and12 dS m^{-1}.

Number of spikes plant^{-1}

Although number of spikes plant^{-1} decreased with an increase in EC levels in both crop species, no significant differences were recorded when EC level increased from 1.6 to 9 dS m^{-1} (Table 5.10), and no significant difference was observed between crop species at any of the EC levels.

Spike fresh and dry weight

Spike fresh and dry weights were significantly reduced as the level of EC increased from 1.6 to 12 dS m^{-1} in wheat, while in barley, these spike fresh and dry weight tended to increase as the level of EC was increasing from 1.6 to 6 dS m^{-1} (Table 5.10). However, in the case of barley, no significant differences were recorded regarding both parameters when EC was increased from 1.6 to 9 dS m^{-1} while in wheat this trend was only found in spike dry weight.

At EC level of 1.6 dS m^{-1}, wheat recorded a higher spike fresh weight and spike dry weight with mean values of 6.48 g $plant^{-1}$ and 1.52 g $plant^{-1}$ compared to barley with mean values of 2.59 g $plant^{-1}$ and 0.73 g $plant^{-1}$ respectively. Although no significant difference was observed at EC level of 12 dS m^{-1}, barley recorded the highest spike fresh and dry weight as compared to wheat.

5.3.4 Fourth sampling (150 days after planting)

At maturity (150 days after planting), wheat and barley differed significantly with regard to above ground dry weight (DW $plant^{-1}$), dry weight of the root (RDW), number of spikes $plant^{-1}$, number of grains $spike^{-1}$ and 1000-grain weight (Table 5.11). The EC level had a significant effect on all growth parameters while significant crop x EC level interaction was found with regard to RDW, number of spikes $plant^{-1}$, number of grains $plant^{-1}$ and number of grain $spike^{-1}$. For this reason, main effects will not be discussed for these parameters.

Table 5.11: Significance levels (Pr>F) of selected growth parameters of wheat and barley as affected by main effects (crops and EC levels) and the interaction between main effects.

Source of Variation	PDW (g)	RDW (g)	Spike number $plant^{-1}$	Spike Dry weight (g $plant^{-1}$)	Grain number $plant^{-1}$	GW $plant^{-1}$ (g)	Grain number $spike^{-1}$	1000-GW (g)
Crop	0.00	0.00	0.00	0.57^{ns}	0.99^{ns}	0.13^{ns}	0.00	0.03
EC Level	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crop x EC Level	0.50^{ns}	0.00	0.00	0.09^{ns}	0.03	0.06^{ns}	0.00	0.76^{ns}

Significant at the 0.05 probability level. ^{ns} not significant.

PDM (plant dry weight). RDW (root dry weight). GW (grain weight)

5.3.4.1 Effect of crop species on growth parameters

At 150 days after planting, mean dry weight of spikes (DW spike) and grain weight $plant^{-1}$ did not differ significantly between wheat and barley while, significant differences were observed with dry weight $plant^{-1}$ (DW $plant^{-1}$) and 1000-grain weight (Table 5.12).

Barley recorded the highest DW $plant^{-1}$ with mean value of 16.83 g $plant^{-1}$ as compared to wheat with mean value of 12.22 g $plant^{-1}$. As for 1000-grain weight, wheat recorded the highest with mean value of 39.79 g compared to 35.01 g of barley.

Table 5.12: Effect of crop species on selected growth parameters as measured at 150 days after planting

Crop	DW Plant^{-1} (g)	RDW (g)	Spike number plant^{-1}	DM Spike	Grain number plant^{-1}	Grain weight plant^{-1}	Grain number spike^{-1}	1000-GW (g)
Wheat	12.22^{b}	1.84^{b}	3.45^{b}	8.63^{a}	146.35^{a}	6.10^{a}	36.70^{a}	39.79^{a}
Barley	16.83^{a}	3.62^{a}	12.25^{a}	8.92^{a}	146.20^{a}	5.76^{a}	11.35^{b}	35.01^{b}

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

5.3.4.2 Effect of EC level on selected growth parameters of wheat and barley

Above ground dry weight plant^{-1}

The above ground dry weight plant^{-1} (g plant^{-1}) showed a significant decrease with all increases in EC levels measured at 150 days after planting (Table 5.13). The heaviest dry weight of 27.00 g plant^{-1} was recorded at an EC level of 1.6 dS m^{-1} and the lightest with mean value of 3.05 g plant^{-1} at an EC level of 12 dS m^{-1}.

Spike dry weight

Similar to above ground dry weight, the spike dry weight (g plant^{-1}) also showed a significant decrease with all increases in EC levels (Table 5.13), ranging from 16.28 g plant^{-1} at EC level of 1.6 dS m^{-1} (control) to 1.41 g plant^{-1} with EC level of 12 dS m^{-1}.

Table 5.13: Selected growth parameters of wheat and barley as affected by EC levels at 150 days after planting.

EC level (dS m^{-1})	Above ground dry weight (g $plant^{-1}$)	Spike dry weight (g $plant^{-1}$)	Grain weight (g $plant^{-1}$)	1000-grain weight (g $plant^{-1}$)
1.6	27.00^{a}	16.28^{a}	11.65^{a}	46.32^{a}
3	20.17^{b}	12.40^{b}	8.82^{b}	39.70^{a}
6	14.53^{c}	9.16^{c}	6.52^{c}	41.05^{a}
9	7.89^{d}	4.63^{d}	2.81^{d}	36.81^{a}
12	3.05^{e}	1.41^{e}	0.71^{d}	23.12^{b}

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

Grain weight plant^{-1}

Although grain weight plant^{-1} showed a decrease with an increase in EC levels from 1.6 to 12 dS m^{-1}, differences were significant only from 1.6 to 9 dS m^{-1} (Table 5.13). Mean grain weight plant^{-1} varied from 11.65 g plant^{-1} (1.6 dS m^{-1}) to 0.71 g plant^{-1} (12 dS m^{-1}).

1000-grain weight

Thousand grain weight also showed a decrease with an increase in EC levels, but no significant differences were recorded when EC level increased from 1.6 to 9 dS m^{-1} (Table 5.13).

5.3.4.3 Effect of crop x EC level interaction on selected growth parameters of wheat and barley.

Significant crop x EC level interactions were found with regard to dry weight of roots (g plant^{-1}), number of spikes plant^{-1}, number of grains plant^{-1} and number of grains spike^{-1} (Table 5.14).

Root dry weight

Although root dry weight (g plant^{-1}) was reduced with increasing EC level in both crop species, no significant differences were recorded when EC level increased from 6 to 12 dS m^{-1} (Table 5.14). However, at an EC level of 1.6 dS m^{-1} barley had a higher root dry weight with mean value of 11.25 g plant^{-1} as compared to wheat with mean value of 5.36 g plant^{-1}.

Table 5.14: Effect of crop x EC level interactions on selected growth parameters of wheat and barley as measured at 150 days after planting.

Crop	EC level ($dS\ m^{-1}$)	Root dry weight ($g\ plant^{-1}$)	Spike number $plant^{-1}$	Grain number $plant^{-1}$	Grain number $spike^{-1}$
Wheat	1.6	5.36^{b}	5.75^{de}	276.75^{a}	48.25^{a}
	3	2.36^{cd}	5.25^{de}	231.00^{ab}	45.25^{a}
	6	1.00^{de}	3.00^{e}	151.00^{cd}	50.50^{a}
	9	0.43^{de}	2.25^{e}	64.75^{ef}	31.25^{b}
	12	0.06^{e}	1.00^{e}	8.25^{f}	8.25^{c}
Barley	1.6	11.25^{a}	19.00^{a}	227.75^{ab}	12.00^{c}
	3	4.49^{bc}	16.75^{ab}	207.50^{ac}	12.75^{c}
	6	1.50^{de}	13.25^{bc}	163.75^{bc}	13.00^{c}
	9	0.70^{de}	8.5^{cd}	91.50^{de}	10.75^{c}
	12	0.18^{de}	3.75^{de}	40.50^{ef}	8.25^{c}

Means within each column followed by the same letter are not significantly different at the 5 % probability level.

Number of spikes plant^{-1}

The number of spikes plant^{-1} showed a decrease with an increase in EC levels in barley, but not in wheat (Table 5.14). At EC levels of 1.6, 3, 6 and 9 dS m^{-1}, number of spikes of barley crop was significantly higher than that of wheat, but no significant difference was shown at 12 dS m^{-1}.

Number of grains plant^{-1}

The number of grains plant^{-1} were also significantly reduced with increasing EC level in both crop species but with no significant effects in both crop species when EC level increases from 1.6 to 3 dS m^{-1} and 9 to 12 dS m^{-1}, as well as at 3 to 6 dS m^{-1} for barley only (Table 5.14). No significant differences were shown between wheat and barley at any of the EC levels tested.

Number of grains spike^{-1}

Number of grains plant^{-1} showed no significant decrease in barley with an increase in EC levels and only at EC levels 9 and 12 dS m^{-1}in wheat (Table 5.14). At EC levels from 1.6 to 9 dS m^{-1}, number of grains spike^{-1} of wheat was significantly higher than that of barley, but at EC level of 12 dS m^{-1}, no significant difference was observed.

5.4 Discussion

The growth of the plant in a saline environment is adversely affected and the effects are clearly shown at each of the phenological stages of development such as germination, tillering, booting and grain filling stage (Maas and Grieve 1990). Tolerance towards salinity in different crops is quite variable at different growth stages (Shannon 1984, Akram et al. 2002). In the present study, an investigation was done to determine the effect of salinity stress on South African spring wheat and South African spring barley at the vegetative, reproductive and maturity stage.

Salinity stress caused a significant reduction in leaf area, shoot fresh and dry weight, root fresh and dry weight and number of tillers of both crop species at vegetative stage. The results concurred with the findings of Maas and Grieve (1990), Bharti and Singh (1994), Hajar et al. (1996), Mamo et al. (1996), Murillo-Amador and Trovo-Dieguez (2000), Grieve et al. (2001), Essa (2002), El-Hendawy et al. (2005), Turan et al. (2007), Zhao et al. (2007) and Shahzad et al. (2012). The notable decrease in leaf area may be due to the negative effect of salt on photosynthesis that leads to the reduction of plant growth, leaf growth and chlorophyll content (Netondo et al. 2004). According to Munns et al. (1995), reduction is shoot weights may be due to decreased water potential of rooting medium and growth inhibition related to osmotic effects under saline conditions. The effect of NaCl on fresh and dry weights of plant organs may be positive or negative. These include a study by Abdul Qados (2011) on bean plant, Andriolo et al. (2005) on lettuce and Dantus et al. (2005) on cowpea. According to Nicolas et al. (1994), salt stress at tiller emergence can inhibit their formation and can cause their death at later stages.

Leaf area, shoot fresh and dry weight, root fresh and dry weight, number of spikes plant^{-1} and number of tillers plant^{-1} of both South African spring wheat and barley were reduced with increasing level of EC at the reproductive stage. The present findings are in accordance with previous findings of Kirby (1988), Maas and Poss (1989), Maas et al. (1994), Francois et al. (1994) and Turki et al. (2012).

Spike fresh and dry weight were reduced with increasing EC level in wheat, while in barley these parameters were increased when EC level increased from 1.6 to 6 dS m^{-1}. However, Tammam et al. (2008) in the study of salt tolerance in wheat (*Triticum aestivum* L.) cultivar Banysoif 1, found that the fresh and dry matter of spikes were increased with increasing salinity from 0 mM to 180 mM NaCl recorded at 155 days after planting.

At maturity stage, above ground dry weight, root dry weight, spike dry weight, number of spikes $plant^{-1}$, number of grains $spike^{-1}$, number of grains $plant^{-1}$, grain weight $plant^{-1}$ and 1000-grain weight showed a decrease with increase in EC level in both crop species. Similar results were previously reported (Gill 1979, Hu et al. 1997, Akram et al. 2002, Javed et al. 2003, El-Hendawy et al. 2005, Ahmed 2006, Dixit and Chen 2010, Chaabane et al. 2011, Asgari et al. 2012, Mojid et al. 2013 and Hessini et al. 2015). The reduction in the number of grains $spike^{-1}$ may be due to a shorter spikelet development stage caused by the NaCl stress, which resulted in fewer spikelets per spike (Maas and Grieve 1990), while the reduction in the number of grains $plant^{-1}$ may be due to a reduction in spike and grain production by the plant (Gill 1979). According to Wardlaw et al. (1980), grain weight is largely determined by the duration and rate of grain filling. Therefore, environmental stresses that tend to shorten the grain filling period will significantly reduce the final grain weight (Maas and Grieve 1990). Francois et al. (1986, 1988), reported that salt stress accelerates maturation and grain filling in some cereal crops. For this reason, reduction in grain weight $plant^{-1}$ could be due to a shortened grain filling period (Francois et al. 1994).

It is clear from the results that salinity stress had a significant effect on growth parameters of both crop species measured at different growth stages. Although barley outperformed wheat for most parameters tested and at most stages, these results however did not necessarily indicate differences in salt tolerance between crops as both crop species showed similar reductions with increasing EC levels for most parameters at all growth stages monitored.

5.5 Conclusion

Salinity is a major constraint to crop production especially in arid and semi-arid regions. The focus of this study was to investigate the effect of salinity on the vegetative and reproductive growth and grain yield of South African spring wheat and barley when exposed to increasing EC level due to increasing concentration of NaCl salt. This pot study conducted in the glasshouse showed that salinity had a significant effect on the vegetative and reproductive growth and grain yield of all measured parameters of both wheat and barley.

Although barley generally produced higher dry weights, especially at the early growth stages no clear evidence was found for South African spring barley to be more salt tolerant than South African spring wheat. No significant crop and EC level interaction were shown with regard to grain weight plant^{-1} suggesting no difference in salt tolerance between the tested wheat and barley cultivar. However, when comparing the reduction in grain weight plant^{-1} with increasing EC levels, barley showed a reduction of 19 % compared to 32 % of wheat when EC level increased from 3 to 6 dS m^{-1}. This may have some practical implications when wheat and barley are produced under moderate saline condition.

5.6 References

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CHAPTER 6

Summary and General Conclusions

Due to an increase in human population, the competition for high quality water among the municipal, industrial and agricultural sectors increases. This has resulted in a decreased allocation of fresh water to agriculture and growers are often forced to use water with poor quality to irrigate. In many parts of the world, salinity is one of the main sources of poor water quality. Salinity is a measure of the content of salts in water or soil and it is one of the most important abiotic environmental stresses limiting crop production especially in arid and semi-arid regions. It is expressed in terms of concentration (mg L^{-1}) or electrical conductivity (dS m^{-1}). The aim of this study was to investigate the germination, seedling growth, vegetative growth, reproductive growth and grain yield responses of South African spring wheat and barley to irrigation with saline water.

This study consisted of one incubation trial presented in chapter 3 (Trial 1): "Effect of salinity on the seed germination of wheat and barley cultivars in incubation tests" and two glasshouse trials presented in chapter 4 (Trial 2): "Effect of salinity on seedling growth of wheat and barley grown in pot trials" and chapter 5 (Trial 3): "Effect of salinity on the vegetative and reproductive growth and grain yield of wheat and barley grown in pot trials". All the trials were conducted at the Department of Agronomy at Stellenbosch University. The incubation trial was conducted with three South African spring wheat cultivars (SST 027, SST 056, SST 087) and three South African spring barley cultivars (Hessekwa, Nemesia, Erica) using petri- dishes (9 cm diameter) in the dark at a constant temperature of 20 °C and the trial was laid out as a Complete Randomized Design (CRD) with four replications. The glasshouse trials were conducted with one South African spring wheat cultivar (SST 027) and one South African spring barley cultivar (SVG 13), using pots under temperature controlled conditions (20/15 °C day/night) and a mixture of sand and potting soil in the ratio 1:1 was used as the growing medium. Trial 2 was also laid out as a CRD with four replications while trial 3 was laid out as a complete randomized block design (CRBD) replicated four times.

Effect of salinity at germination stage

After seven (7) days of incubation, the study showed that when EC level was increased from 0 to 20 dS m^{-1}, the final germination percentage (FGP) and salt tolerance (ST) of all wheat and barley cultivars tested were decreased. However, significant reduction was observed at high EC levels only. Germination rate (GR) was also decreased with increasing EC level.

The fastest seed germination rate was recorded at the low EC level (0 dS m^{-1}) while those seeds irrigated with the highest EC level (20 dS m^{-1}) showed the slowest germination rate. Furthermore, the study showed that wheat cultivars recorded faster germination rates when compared to barley cultivars, but no significant differences were shown between cultivars of the same species. For this reason only one South African spring wheat cultivar and one South African spring barley cultivar were used in pot trails.

Effect of salinity at seedling stage

The present study showed that by increasing EC level from 0 dS m^{-1} to 20 dS m^{-1}, shoot length, root length, shoot fresh and dry weight and root fresh and dry weight were reduced in both crop species. At 35 days after planting, mean values for most growth parameters were higher for the barley cultivar SVG 13 compared to the wheat cultivar SST 027. However, the barley cultivar showed superior shoot and root growth only at lower EC levels (0 and 4 dS m^{-1}) and not at higher EC levels. Therefore, little evidence was found to show that barley is more salt tolerance than wheat at the seedling stage. In general, these results indicate that salinity had a significant (P0.05) effect on seedling growth of all measured parameters of both wheat and barley.

Effect of salinity at vegetative, reproductive and maturity stage

The study showed that salinity had a significant (P0.05) effect on the vegetative growth, reproductive growth and grain yield of both wheat and barley. Selected parameters were measured at tillering (28 DAP), booting (54 DAP), flowering (71 DAP) and maturity stage (150 DAP). At all stages, the barley cultivar, SVG 13, showed a higher leaf area, shoot fresh and dry weight and root fresh and dry weight than the wheat cultivar, SST 027. At maturity stage, barley showed a higher above ground dry weight, root dry weight and number of spikes $plant^{-1}$, but wheat produced the highest number of grains $spike^{-1}$, number of grains $plant^{-1}$, grain weight $plant^{-1}$ and 1000-grain weight. These results however did not necessarily indicate differences in salt tolerance as both crop species showed significant reductions in the parameters measured with increasing EC levels.

Conclusions and future research

This study showed that salinity had a negative effect on the germination, seedling growth, vegetative growth, reproductive growth and yield of all South African spring wheat and barley grown in petri-dishes and pots under controlled environmental conditions in this study. No significant differences in salt tolerance between crop species or between different cultivars of the same species were shown, but because only a limited number of cultivars was evaluated it is recommended that more cultivars and especially cultivars from different breeding companies should be tested. Pot trial studies may result in severe root restriction and limited nutrient availability as well as root binding. For this reason, it is recommended that further research be done under natural field conditions (farm trials) to confirm this tendency. Furthermore, research could focus on the water requirements and economics of irrigating these crops. Knowledge of how wheat and barley respond to salinity stress would improve management practices in fields and increase our understanding of salt tolerance mechanisms in these crop species, hence improve their production under irrigation.