THE EFFECT OF WATER QUALITY ON THE GROWTH AND YIELD OF IRRIGATED CROPS

by

SHADRACK BATSILE DIKGWATLHE

Submitted in accordance with the requirements for the degree

Magister Scientae Agriculturae

Department of Soil, Crop and Climate Sciences
(Agronomy)
Faculty of Natural and Agricultural Sciences,
University of the Free State,
Bloemfontein

May 2006

PROMOTER : Dr. G. M. Ceronio
CO- PROMOTER : Prof. L. D. van Rensburg

THE EFFECT OF WATER QUALITY ON THE GROWTH AND YIELD OF IRRIGATED CROPS

ACKNOWLEDGEMENTS…………………………………………………………………... vi
LIST OF FIGURES………………………………………………………………………..vii
LIST OF TABLES…………………………………………………………………….... x

CHAPTER 1
INTRODUCTION……………………………………………..……………………...1.1
1.1 Motivation and Background……………………………………………..…… 1.1
1.2 Problem statement…………………………………………………….………. 1.4
1.3 Overall objective……………………………………………………...……….. 1.4
1.4 Objectives…………………………………………………………......…...1.4

CHAPTER 2
LITERATURE REVIEW……………………………………………………………… 2.1
2.1 Introduction…………………………………………….………………...2.1
2.2 Effect of water quality (salinity) on plant growth…………….………….. 2.2
2.2.1 Principal plant responses to salinity……………………….……. 2.2
2.2.1.1 Osmotic effects…………………………………….………...2.2
2.2.1.2 Specific ion effects and nutrition………………….………...2.5
2.2.1.3 Specific ion toxicity…………………………….………… 2.5
2.3 Effect of salt stress on plants……………………………………….……2.6
2.3.1 Water availability mechanism……………………………………… 2.6
2.3.2 Hormones…………………………………………………...………...2.7
2.3.3 Damage to plant cell and cytoplasmic organelles…………………..2.7
2.3.4 Interference with normal metabolism…………………………... 2.7
2.4 Salt response during plant development……………………………………...2.8
2.4.1 Germination…………………………………………………….......2.8
2.4.2 Shoot development……………………………..………………2.8
2.4.3 Root development…………………………………………….…......2.9

2.5 Crop salt tolerance……………………………………………………….……....2.9
2.6 Factors influencing salt tolerance…………………………………......…..2.13
2.6.1 Soil fertility………………………………………………………… 2.13
2.6.2 Physical soil condition……………………………………..…......2.13
2.6.3 Salt distribution in the profile………………………………….. 2.14
2.6.4 Irrigation methods…………………………………………………2.14
2.6.5 Climate……………………………………………………….……... 2.14
2.6.6 Stage of growth…………………………………………………...2.15
2.6.7 Varieties……………………………………………………...... 2.15
2.7 Quantifying salinity diagnosis……………………………………………..2.15
2.8 REFERENCES……………………………………………………......2.17

CHAPTER 3

WHEAT (*Triticum aestivum* L.) GROWTH AND YIELD RESPONSE TO SALINE IRRIGATION WATER UNDER CONTROLLED CONDITIONS

3.1 ABSTRACT…………………………………………………………….……3.1
3.2 INTRODUCTION…………………………………………………………...3.2
3.3 MATERIALS and METHODS………………………………………………..3.3
3.3.1 Irrigation water solution…………………………………….…… 3.3
3.3.2 Germination experiment…………………………………….… 3.4
3.3.3 Glasshouse pot experiment……………………………………..3.5
3.4 RESULTS and DISCUSSION………………………………………….…...3.6
3.4.1 Germination percentage, coleoptile and root length……………….…3.6
3.4.2 Response of wheat at tillering, flag leaf and maturity…………….…3.7
3.4.2.1 Below ground plant response………………………………..3.7
3.4.2.2 Above ground plant response………………………………..3.9
3.4.2.3 Yield and yield components……………………………...3.11
3.5 CONCLUSIONS……………………………………………………... 3.14
3.6 REFERENCES…………………………………………………………..3.15

CHAPTER 4

MAIZE (*Zea mays* L.) GROWTH REPONSE TO SALINE IRRIGATION WATER UNDER CONTROLLED CONDITIONS

4.1 ABSTARCT……………………………………………………………….……4.1
4.2 INTRODUCTION……………………………………………………………...4.2
4.3 MATERIALS and METHODS..………………………………………….....4.3
4.3.1 Irrigation water solution……………………………………......…4.3
4.3.2 Germination experiment……………………………………………..4.3
4.3.3 Glasshouse pot experiment…………………………………………..4.3
4.4 RESULTS and DISCUSSION……………………………………….……...4.4
4.4.1Germination percentage, coleoptile and root length………………..…4.4
4.4.2 Response of maize at different periods during the vegetative stage ……………………………………………………………………..4.5
4.4.2.1 Below ground plant response………….........….……………...4.5
4.4.2.2 Above ground plant response ………………………………4.7
4.5 CONCLUSIONS……………………………………………………….…….. 4.11
4.6 REFERENCES………………………………………………………….….4.12

CHAPTER 5

PEAS (*Pisum sativum* L.) AND BEANS (*Phaseolus vulgaris* L.) GROWTH AND YIELD RESPONSE TO SALINE IRRIGATION WATER UNDER CONTROLLED CONDITIONS

5.1 ABSTARCT……………………………………………………………….……5.1
5.2 INTRODUCTION……………………………………………………………...5.2
5.3 MATERIALS and METHODS…………………………………………….....5.3
5.3.1 Irrigation water solution………………………………............…… 5.3
5.3.2 Germination experiment……………………………………….…… 5.4
5.3.3 Glasshouse pot experiment………………………………………….. 5.4
5.4 RESULTS and DISCUSSION……………………………………….…..…. 5.5
5.4.1 Germination percentage, hypocotile and root length……………..…...5.5
5.4.2 Response of beans and peas at vegetative, flowering and maturity stages………………………………………………………………… .5.6
5.4.2.1 Below ground plant response…………………………….….5.6

5.4.2.2 Above ground plant response……………………………......5.9
5.4.2.3 Yield and number of pods per plant………………………..5.11
5.5 CONCLUSIONS…………………………………………………….….…5.13
5.6 REFERENCES……………………………………………………………..5.14

CHAPTER 6
COMPARISON OF THE CROP RESPONSE TO VARIOUS SALINITY LEVELS
6.1 ABSTRACT………………………………………………………………….6.1
6.2 INTRODUCTION…………………………………………………………...6.2
6.3 MATERIALS and METHODS……………………………………………. 6.3
6.4 RESULTS and DISCUSSION……………………………………………... 6.4
6.4.1 Germination experiment…………………………………………. 6.4
6.4.1.1 Quantitative growth analysis on germination…………….……6.5
6.4.1.2 Qualitative growth analysis on germination………......……6.5
6.4.2 Glasshouse pot experiments……………………………….……... 6.6
6.4.2.1 Effect of increasing EC_i levels on selected plant indicators……………………………………………...6.6
6.4.2.1.1 Relative leaf area…………………………………..6.8
6.4.2.1.2 Relative root mass.......................................……..6.9
6.4.2.1.3 Relative biomass………………………………….....6.11
6.4.2.1.4 Relative seed yield………………………………..6.12
6.4.2.2 Effect of soil water salinity on growth and water use.........6.14
6.4.2.2.1 Water use and salt accumulation in pots…………6.14
6.4.2.2.2 Relative biomass……………………........…... 6.15
6.5 CONCLUSIONS……………………………………………………... 6.17
6.6 REFERENCES……………………………………………………………..6.19

CHAPTER 7
GENERAL CONCLUSIONS AND RECOMMENDATIONS…………………………7.1
7.1 CONCLUSIONS……………………………………………………..….... 7.1
7.2 RECOMMENDATIONS……………………………………………….....7.2
7.3 FUTURE RESEARCH ………………..……………………………...……7.2

CHAPTER 8

SUMMARY……………………………………………………………………………8.1

OPSOMMING………………………………………………………………………...8.3

ACKNOWLEDGEMENTS

My Heavenly Father, for giving me strength and power to complete this study.

I would like to express my sincere thanks to the following persons and institutions:

My promoter, Dr GM Ceronio, for his immeasurable guidance, dedication, patience and also for his support during difficult times of my life.

My co-promoter, Prof LD van Rensburg, for his valuable contribution and efforts to finalise this study.

Prof CC du Preez, for arranging financial matters during the time of this study.

The Department of Soil, Crop and Climate Sciences and its staff for providing excellent research facilities.

Mrs Coetźee for assisting in the measurements of the root length for all crops.

WRC - Water Research Commission for funding the study and also for the opportunity to be part of a research team.

NDA - National Department of Agriculture and CCETSA - Cannon Collins Educational Trust of Southern Africa for their financial contribution during 2005.

SASCP-South African Society of Crop Production for their financial contribution.

My family and friends for their support and motivation and also for understanding that the time I spent without them was for a good harvest at the end of the season.

‘Malerato Violet Rasello, mother of my son Tshepo, for her love and endless care.

To my late mother, Moipone Selina Dikgwatlhe, who laid a foundation of who I am today and also who would have liked to see me making something out of myself one day.

LIST OF FIGURES

CHAPTER 2

Figure 2.1 Hypothetical yield response of crops to increasing salinity on relative basis (Adapted from Maas & Hoffman, 1977)……………………………………..2.11

CHAPTER 3

Figure 3.1 The effect of differing EC_i levels (irrigation water salinity) on root length and root mass at different stages of growth (tillering, flag leaf and maturity are represented by a solid, dashed and dotted line).……………………..……......3.8

Figure 3.2 The effect of differing EC_i levels (irrigation water salinity) on leaf area and plant height at different stages of growth (tillering, flag leaf and maturity are represented by a solid, dashed and dotted line)……………………………... 3.11

Figure 3.3 The effect of differing EC_i levels (irrigation water salinity) on biomass, seed yield and yield components at maturity [biomass and seed yield are represented by a solid and a dashed line (A), whereas head number, seed mass ear^{-1} and 100 seed mass are represented by a solid, dashed and dotted line (B)]………….. 3.12

CHAPTER 4

Figure 4.1 The effect of differing EC_i levels (irrigation water salinity) on root length and root mass at different stages growth (2, 4 and 6 wae are represented by a solid, dashed and dotted line)……......………………………………………...….. 4.7

Figure 4.2 The effect of differing EC_i levels (irrigation water salinity) on plant height and stem diameter at different stages growth (2, 4 and 6 wae are represented by a solid, dashed and dotted line)……………………………………………….....4.8

Figure 4.3 The effect of differing EC_i levels (irrigation water salinity) on leaf area and biomass yield at different stages growth (2, 4 and 6 wae are represented by a solid, dashed and dotted line)…………………………………………….....4.10

CHAPTER 5

Figure 5.1 The effect of differing EC_i levels (irrigation water salinity) on root length and root mass at different stages of growth on peas (5 wae, flowering and maturity are represented by a solid, dashed and dotted line)…………………………...5.7

Figure 5.2 The effect of differing EC_i levels (irrigation water salinity) on root length and root mass at different stages of growth on beans (5 wae, flowering and maturity are represented by a solid, dashed and dotted line)…………………………...5.7

Figure 5.3 The effect of differing EC_i levels (irrigation water salinity) on leaf area and biomass at different stages of growth on peas (5 wae, flowering and maturity are represented by a solid, dashed and dotted line)………………………………5.11

Figure 5.4 The effect of differing EC_i levels (irrigation water salinity) on leaf area and biomass at different stages of growth on beans (5 wae, flowering and maturity are represented by a solid, dashed and dotted line)…………………………..5.11

Figure 5.5 The effect of differing EC_i levels (irrigation water salinity) on pod number and seed yield for peas (A) and beans (B) (seed yield and pod number are represented by a solid and dashed line)……………………………………5.13

CHAPTER 6

Figure 6.1 Response of relative leaf area of the selected crops to increase in different EC_i levels. The vertical line (l) indicates the onset of the first significant difference ($P \leq 0.05$) compared to the control……………………………………………... 6.8

Figure 6.2 Response of relative root mass of the selected crops to increase in different EC_i levels. The vertical line (l) indicates the onset of the first significant difference ($P \leq 0.05$) compared to the control…………………………………..…..6.10

Figure 6.3 Response of relative biomass production of the selected crops to increase in different EC_i levels. The vertical line (|) indicates the onset of the first significant difference ($P \leq 0.05$) compared to the control…………………... 6.11

Figure 6.4 Response of relative seed yield of the selected crops to increase in different EC_i levels. The vertical line (|) indicates the onset of the first significant difference ($P \leq 0.05$) compared to the control……………….………………………….. 6.13

Figure 6.5 Relationship between irrigation water salinity (EC_i) and soil salinity (EC_e) in the pots…………………………………………………..................………. 6.15

Figure 6.6 Effect of soil salinity induced osmotic stress on the relative biomass production of selected crops. Note that non-stress treatments were included in the regression.………………………………………………………………… 6.16

LIST OF TABLES

CHAPTER 2

Table 2.1 Salt tolerance of some agronomic crops. Crops used in this study are highlighted in bold (After Maas, 1986)……………………………………………………..2.12

CHAPTER 3

Table 3.1 The electrical conductivity (EC_i, mS m^{-1}), sodium adsorption ratio (SAR) and amount of different salts to prepare the required irrigation water quality treatments…………………………………………..………………..…..3.4

Table 3.2 Effect of different EC_i levels on germination percentage, coleoptile and root length of wheat…………………………………………………………..3.7

Table 3.3 Statistical results of the response of wheat at tillering, flag leaf and maturity to saline irrigation water as indicated by various plant indicators on a relative scale……………………………………………………......…………….3.9

CHAPTER 4

Table 4.1 Effect of different EC_i levels on germination percentage, coleoptile and root length of maize…………………………………………………………..4.4

Table 4.2 Statistical results of the response of maize at two weeks, four weeks and six weeks after emergence to saline irrigation water by various plant indicators on a relative scale…………………………………………………………………..4.6

CHAPTER 5

Table 5.1 The electrical conductivity (EC_i, mS m^{-1}), sodium adsorption ratio (SAR) and amount of different salts to prepare the required irrigation water quality treatments……………………………………………………..…………5.4

Table 5.2 Germination percentage, hypocotile and root length affected by different EC_i levels for peas and beans……………………………………………..……5.6

Table 5.3 Statistical results of the response of peas at early vegetative growth, flowering and maturity stage to saline irrigation water as indicated by various plant indicators on a relative scale…………………………………..5.8

Table 5.4 Statistical results of the response of beans at early vegetative growth, flowering and maturity stage to saline irrigation water as indicated by various plant indicators on a relative scale…………………………………………………….....5.9

CHAPTER 6

Table 6.1 The effect of increasing irrigation water EC levels on the germination percentage, coleoptile or hypocotile length and root length of the selected crops………………………………………………………………………………. 6.4

Table 6.2 Summary of the level from where salinity significantly reduced the different plant indicators of the selected crops……………………………………….……………6.7

Table 6.3 Relative leaf area reduction (%) of selected crops at different EC_i levels……………………………………………………………………………6.9

Table 6.4 Relative root mass reduction (%) of selected crops at different EC_i levels………………………………………………………………………... 6.10

Table 6.5 Relative biomass reduction (%) of selected crops at different EC_i levels………………………………………………………………………... 6.12

Table 6.6 Relative yield reduction (%) of selected crops at different EC_i levels………………………………………………………………………... 6.13

Table 6.7 Water use efficiency (WUE, g biomass per kg water applied of the different crops in the glasshouse experiments……………………………………………..............6.15

Table 6.8 Threshold EC_e (mS m^{-1}) and slope values for the selected crops according to the regression analysis of the relationship between the relative biomass and soil salinity (EC_e) of the saline irrigation water treatments………………….………..6.16

CHAPTER 1

INTRODUCTION

1.1 Motivation and Background

In the semi-arid parts of the world, available soil water derived, from rain or from underground water, is inadequate to sustain the water requirements for optimum plant life during the growing season. Such deficiencies can be supplemented through irrigation (Shainberg and Oster, 1978). The importance of irrigation in the world's agriculture is rapidly increasing and although it is practised on a large scale mainly in arid and semi-arid zones, supplementary irrigation is also becoming feasible in sub-humid regions. Undoubtedly soil salinity is the most prevalent and widespread problem limiting crop productivity in irrigated agriculture (Shainberg and Shalhevet, 1984; Szabolcs, 1986). It has therefore attracted the attention of the modern scientific community since the advent of modern agronomic research.

Large areas of land are available for crop production in the arid and semi-arid regions, provided that irrigation can be made feasible, but much of this land has the constraint of actual or potential salinity (Chabbra, 1996). In some parts of the world, land that was once agriculturally productive has been abandoned due to induced salinity that occurred through mismanagement and incorrect irrigation practices with poor water quality (Talsma and Philip, 1971). The unreliability and erratic occurrence of rainfall makes irrigation a vital component of the agricultural industry in South Africa. This will require not only the availability of water, but also the suitability thereof. In fact, in time water quality may become a more important factor than quantity in some areas of the country.

Agriculture, especially irrigation farming is the largest consumer of available water in South Africa (Department of Water Affairs and Forestry-DWAF, 1996). Irrigation water is used to supply water requirements of a wide variety of crops under widely varying degrees of intensification, using a range of different distribution and irrigation systems. One of the major concerns is the control of salinity both in the soil and the water. According to Rhoades and Loveday (1990), the spread of salinity affect not only existing irrigation schemes, but also more recently developed areas. Thus future irrigation practices will cause the irrigated soil to be more affected by excess soluble salts, which will affect crop growth (Szabolcs, 1989; Hu, Camp and Schmidhalter, 2000; Sairam, Rao and Srivastava, 2002). Approximately 50% of all existing irrigation schemes, worldwide totalling 250 million hectares are seriously affected by salinity and water logging and 10 million hectares of irrigated lands are abandoned annually (Szabolcs, 1989).

Salinisation is the increase in concentration of total dissolved salts in both soil and water (Shainberg and Oster, 1978; Frenkel, 1984; Szabolcs, 1989; Tanji, 1990). Land and water resources can be salinised by natural processes or by human activities and therefore serious water quality problems may occur where water is used for irrigation (Szabolcs, 1989; Tanji, 1990).

The deterioration in water quality is often ascribed to upstream irrigation activities as was reported in a recent study for the lower Vaal River and its tributones in South Africa by Du Preez, Strydom, Le Roux, Pretorious, Van Rensburg and Bennie (2000). In this report it was concluded that the deterioration of water quality of the lower Vaal, Harts, Modder and Riet Rivers can mainly be attributed to irrigation activities upstream. If the deterioration of water quality continues for the next 50 years, at the same rate as in the past 30 years, the water of the lower Harts and lower Modder Rivers will become unsuitable for irrigation.

According to Herold and Bailey (1996), water quality varies to such an extent that salinisation of high potential soil, with consequent damage to crops occur from time to time. Land degradation is a principal constraint in meeting the needs of world food production and a major factor contributing to land degradation is soil and water salinisation (Van Hoorn, 1991). Moreover, the continuing deterioration of the quality of both surface water and ground water, coupled with the increased use of brackish water, industrial and municipal waste water for irrigation has enhanced salinisation (DWAF, 1996).

Salinity is a serious problem where irrigation water has a high salt content. Quality of irrigation water is of particular importance in arid and semi-arid climates and salts applied with irrigation water tend to accumulate in the soil profile (Frenkel and Meiri, 1985). Water used for irrigation may contain up to 3000 g m^{-3} (0.3%) salts, compared to 5 – 40 g m^{-3} of rainwater (Shainberg and Oster, 1978). Therefore, the application of 1000 mm of irrigation water per annum containing 0.1% salts, could introduce 10 tons of salt to a hectare of land.

Continued irrigation without leaching will result in a rapid accumulation of salts; 50 years of irrigation will provide 500 tons of salts per hectare and this will introduce osmotic potentials that are devastating to almost all non-halophytes. The process of salt accumulation is a global problem. In some countries the problem is localised, whereas in others 40 - 50% of the total land surface is already salt affected. Backeberg, Bembridge, Bennie, Groenewald, Hammes, Pullen and Thompson (1996) estimated that 10% of South African irrigated land is severely waterlogged or salt affected, with another 10% slightly to moderately affected. Thus 260 000 ha of the 1.3 million ha irrigated land in South Africa was salt affected or water logged by 1990.

Plants differ in their ability to tolerate the harmful effects of salinity in the field (Maas and Hoffman, 1977; Maas, 1986). The general effect of high salt content in the soil results in dwarfed, stunted plants (Meiri and Levy, 1973; Meiri and Shalhevet, 1973). As the salt content increases, the stunting becomes more noticeable and the leaves of plants become dull coloured, often bluish green and coated with a waxy deposit (Shainberg and Oster, 1978). The soluble salts can affect growing plants in two ways i.e. specific effects due to particular ions being harmful to the crop and the general effect due to the raising of the osmotic pressure of the solution around the crop roots (Lynch, Polito and Läuchli, 1989; Maas and Poss, 1989; Saqib, Akhtar and Qureshi, 2004b).

The use of saline water may result in the reduction of crop yields (Maas, 1986; Maas, 1990; Rhoades and Loveday, 1990; Akhtar, Gorham and Qureshi, 1994; Saqib, Akhtar and Qureshi, 2004a). The estimation of absolute crop yield reduction as a result of water quality deterioration was identified as a phenomenal problem and it is essential that the effect of the observed deterioration of the down stream quality of irrigation water on crop production should be investigated. This study will focus on crops that are of major importance in the mentioned irrigation areas of South Africa namely, wheat, maize, peas and dry beans. These are crops of worldwide importance and have been used for various purposes that include human consumption, animal consumption, and after harvesting the stover can be used as organic manure supplying nutrients to succeeding crops and improves the fertility level of the soil.

1.2 Problem statement

Some farmers, especially those at the lower section of the tributones to the lower Vaal River system, experience reduced yields induced by salt loads accumulated in the irrigated soil. A preliminary investigation by Du Preez *et al.* (2000) using international salinity indicators concluded that serious damage to crops can be expected in future if irrigation water deteriorates at the projected rates. Little or no quantitative information on the subject is available for South African conditions. Therefore the study will investigate the response of crops to salinity using deteriorating water quality levels under controlled conditions. The study was also part of the Water Research Commission project titled: *The effect of irrigation water salinity on the growth and water use of selected crops.*

1.3 Overall objective

To investigate the effects of irrigation water quality on the establishment, growth and yield of irrigated field crops, viz. wheat, maize, dry beans and peas.

1.4 Objectives

- To quantify the effect of irrigation water quality on the establishment, growth and yield of selected crops.
- To compare the responses of selected crops to different water qualities.
- To determine at what level of deteriorating irrigation water quality the crops show an inhibition.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

According to DWAF (1996), water quality describes the physical, chemical and aesthetic properties of water that determines its fitness for a variety of uses for the protection of aquatic ecosystems and most of the properties are controlled by constituents, which are either dissolved or suspended in water. The composition of dissolved constituents in water determines its quality for irrigation use, hence quality of irrigation water is an important consideration in any appraisal of salinity conditions in an irrigated area (Richards, 1954). Salinity is a major abiotic stress reducing yield of a wide variety of crops all over the world. The resistance in plants to overcome this abiotic stress is usually quantified in terms of survival rate and or growth abilities under stress conditions (Russell, 1973).

Since water is the most important input for realising sustainable agricultural production, its management and quality are intimately related to the development of salinity (Chabbra, 1996). Irrigation, which is one of the oldest methods used in agriculture, has a history of both favourable and unfavourable results (Szabolcs, 1989). Shainberg and Oster (1978) suggested that although irrigation has been practised for several millennia, it was only during the previous century that the importance of the quality of irrigation water has been recognised. According to Fireman and Kraus (1965), irrespective of their sources, all the natural waters contain dissolved salts, hence the quality of these salts depend on the origin and source of water.

According to Herold and Bailey (1996), water quality is becoming an increasing concern to irrigation, both from a supply viewpoint and with respect to the environmental impacts of irrigation. Therefore, considerable attention is given to the environmental aspects of water quality, including the possible presence of minute amounts of potentially harmful substances. With intensification of water use in South Africa, the general quality of water, both surface and ground water declined (DWAF, 1996). The most important factor in determining the fitness (quality) of irrigation water is salinity. This being the most important factor and with the use of other less important factors an attempt has been made to classify irrigation water quality (Bresler, McNeal and Cater, 1982).

2.2 Effect of water quality (salinity) on plant growth

Salinity seriously constrains crop yield in irrigated agriculture throughout the world. Yield is affected as most of the applied salts are retained in the soil when the water is taken up by plants and the remaining water becomes less available to plants (Ayers and Westcot, 1976). When total dissolved salts in water are high enough, the negative effect of irrigation with such water can be immediate, and alternatively salts will accumulate in the soil. Generally, the plants suffer a slow death with an increase in soil salinity. According to Maas (1986), irrigation water quality can have a profound impact on crop production and understanding of irrigation water quality and its potential negative impacts is essential to avoid problems and to optimise production.

2.2.1 Principal plant responses to salinity

When water is removed from the soil through transpiration or by evaporation from the soil surface, the salt content of the soil solution in the root zone rises with 2 to 5 times that of the irrigation water (Shainberg and Oster, 1978; Chabbra, 1996). Consequently the osmotic potential of the water drops (Läuchli and Epstein, 1990), while the concentration of potentially toxic ions increases (Abrol, Yadav and Massoud, 1988). If growth depression is attributable to a decrease in osmotic potential, it is called an osmotic effect. If it is due to concentration of specific ions, then it is called a specific ion effect, which leads to toxicity and eventually causes nutritional imbalances.

2.2.1.1 Osmotic effects

Läuchli and Epstein (1990) and Munns (2002a) stated that it has been known for a long time that a close relationship exists between the osmotic potential of the soil solution and plant growth. Growth is reduced as the osmotic potential decreases to critical values that influence the availability of water to plants. If the osmotic potential of the medium becomes lower than that of the plant cells, the latter will suffer osmotic desiccation (Chabbra, 1996; Saqib *et al.*, 2004a, b). Therefore, when the osmotic potential of the root medium decreases without the corresponding decrease in the root water potential, the gradient of water flow from the soil to the roots is reduced (Shainberg and Oster, 1978). It can be expected that the lower limit of plant available water will be affected so that the total available water becomes less as the salt content of the soil increases.

According to Chabbra (1996), irrigated agriculture worldwide depends on adequate high quality supplies. As the level of salt increases in an irrigated source, the quality of that water for plants decreases. Thus excess saline water is a constant threat to crop production, because as the crops use irrigation water, the soil salinity increases rapidly with depth as a result of extra salts added by the water (Abrol *et al.,* 1988; Ramoliya and Pandey, 2001). Ayers and Westcot (1976) suggested that a wide spectrum of problems might be encountered where irrigation water does not meet the requirements for optimal crop growth as the salt concentration throughout the soil profile increases between applications with poor water quality.

The effects of salts are manifested by loss in stand, reduced rates of plant growth, reduced yield more than 25%, and in severe cases total crop failure (Shainberg and Oster, 1978; Rhoades and Loveday, 1990). During germination and establishment of seedlings, only salinity of the topsoil affects the plants (Van Hoorn, 1991; Chabbra, 1996). Adding salt to the growth medium result in an increase in the concentration of specific ions that cause salinisation, a reduction in the osmotic potential and consequently the water potential of the medium (Munns, 2002a). These negative effects are manifested in the application of irrigation water with a total salt concentration of 5-10 g ℓ^{-1}. Maas (1990), documented that irrigation with saline water will induce soil salinity, which results in the reduction of crop yields once a threshold salinity, which is specific for each crop, is exceeded. The salt content in the root zone increases with depth, while close to the surface it is similar to that of the irrigation water. Since plants actively absorb water and leave most of the salts behind, salinity within the root zone will accumulate to levels at which the osmotic effect will hamper water uptake by plants (Chabbra, 1996).

Frenkel and Meiri (1985), suggested that salinity effects on commercial yields are of primary importance and that the crop responses to soil salinity is the basis of selection and management under given saline conditions. According to DWAF (1996), the accumulation of salts results when plants transpire and the majority of salts remain in the soil solution. Over time, salts may concentrate to such an extent that it inhibits germination, seedling establishment, vegetative growth, yield and quality of produce. Excess salinity in general reduces plant growth rate, due to the increase in energy used by plants to acquire water from the soil and make the biochemical adjustments necessary to survive (Maas, 1990; Lynch *et al.,* 1989; Munns, 2002a, b; Saqib *et al.,* 2004b). Suppression of growth increases as salinity increases until the plant dies because the plant is responsive to salinity in that part of the root zone where maximum water uptake occurs (Hall, 2001).

Water moves into the plant roots by a process known as osmosis, which is controlled by the relative level of salts in the soil water and the water contained in the plant (Abid, Qayyum, Dasti and Wajid, 2001). If the level of salts in the soil is too high, water may flow from the plant roots back into the soil. This results in dehydration of the plant (plasmolysis of cells in severe cases) causing a decline in yield or even death of the plant and crop yield losses may even occur though the effects of salinity may not be obvious (Ghassemi, Jakeman and Nix; 1995; Munns, 2002a).

According to Maas and Hoffman (1977), plants respond similarly to salinity over a fairly wide range of combination of salts. Salinity affects plant performance differently at different stages of growth, e.g. most plants are tolerant during germination but become sensitive during stages of emergence and early seedling growth and plant stand can be seriously affected at this stage (Maas, 1990).

Chabbra (1996) revealed that, soil salinity due to poor water quality reduced transpiration and respiration, water uptake, growth, destroyed the hormonal equilibrium, reduced the net photosynthesis rate, nitrate uptake and this caused dwarf like plants. A high salt concentration in the soil body creates a physiological drought for crops planted therein (Munns, 2002b). Additionally certain salts may be toxic to the plants or may upset the nutritional balance if they are present in excessive amounts (Abid *et al.,* 2001). Crops growing in a saline soil typically show uneven growth and may exhibit other symptoms induced by salinity such as stunted growth or unusual small leaves of a deep blue-green colour (Abrol *et al*., 1988). Though the osmotic effect is of primary importance, the effect of specific ions has to be taken into account.

2.2.1.2 Specific ion effects and nutrition

Injury or growth depression that cannot be accounted for on the basis of the osmotic potential will be referred to as the effect of specific ions (Richards, 1954). Higher concentrations of individual ions in the root environment may impose danger to the plant or may retard the uptake of and metabolism of essential plant nutrients (Chabbra, 1996). Often the total salt concentration is not high enough per se to affect growth seriously, but there may be additional adverse effects by particular ions (Fireman and Kraus, 1965).

One of these adverse effects is nutritional disturbances under saline conditions. Nutritional disturbances associated with salinity are limited to a small number of crops, in some cases only particular varieties, usually vegetables (Richards, 1954; Fireman and Kraus, 1965; Chabbra, 1996). These detrimental nutritional effects are usually due to high concentration of ions, which may interfere with the absorption of other nutrients (Chabbra, 1996). An example of this is the inhibitory effect salinity has on the uptake of macronutrients such as nitrogen and phosphorus (Abu-Awwad, 2001). Fertilisation usually improves the plant's ability to tolerate salts.

A lower assimilation of macronutrients correlated well with reduced plant growth. In most of the cases nutritional disturbances due to salinity are relatively minor and they can frequently be overcome by adding that particular deficient nutrient to the plant (Fireman and Kraus, 1965). High salinity may also interfere with the growth and activity of soil microbes and therefore indirectly affect the nutrient availability (Abrol *et al*., 1988).

2.2.1.3 Specific ion toxicity

Toxic ion effect is essentially similar to the specific ion effect but differentiation has been made on the basis of the amount of the adverse ion required to produce harmful effects (Chabbra, 1996). Even at extreme low concentrations "toxic" ions injure the plants and may be toxic to various plant physiological processes. Generally, the effect on growth is proportional to the amount of accumulated ions (Fireman and Kraus, 1965). Ions that may have toxic effects, even at concentrations of only a few mg ℓ^{-1} are boron, lithium and selenium (Chabbra, 1996).

Plants may often accumulate elements in their leaves without showing apparent damage (Abrol *et al*., 1988). However, when toxicity symptoms are present, most crops respond to a total concentration of ions in the growth medium, rather than to any specific ion (Ghassemi *et al.*, 1995).

2.3 Effect of salt stress on plants

2.3.1 Water availability mechanism

Reduction in water availability to the plant and disturbed water balance in the plant cells will result in reduced turgor pressure and a lower growth rate (Meiri and Shalhevet, 1973). The effect of salts on the water balance of cells has been attributed to two causes – the change in the water potential gradient between the growth medium and the plant cells and the salt distribution within the plant tissue.

Under saline conditions, the distribution of salts within plant cells may also result in turgor reduction and growth inhibition (Meiri and Shalhevet, 1973; Chabbra, 1996). If the rate of salt supply from the source exceeds the rate of ion uptake by the cells, the salt concentration in the root-soil contact area will build up and the potential of the cell wall will be reduced causing desiccation of the vacuole, reduction of turgor pressure and in extreme cases, even death of plants (Munns, 2002b). However, growth retardation as a result of osmotic effects was not necessarily followed by a similar reduction in the transpiration rate. Water availability in the soil relates to the total sum of the matric and osmotic potential (Chabbra, 1996; Munns, 2002b).

With an increased soil salt concentration, the osmotic potential of the soil decreases and plants are not able to extract the water as easily as from a relatively non saline soil, because the soluble salts exert this potential over and above the matrix potential that already exist in the soil (Abrol *et al.*, 1988; Chabbra, 1996). According to Richards (1954) and Abrol *et al.* (1988) the osmotic balance of the soil is affected as a result of water that moves from an area of low osmotic potential (high salt content) to an area of high osmotic potential (low salt content). This reduces plant vigour and growth and eventually symptoms that are similar to that caused by drought are observed.

According to Meiri and Shalhevet (1973), salinity effect on a plant is brought by a disturbance of plant water balance and induced conditions of physiological drought. Several other researchers have pointed out the relationship between water stress and salinity (Fireman and Kraus, 1965; Meiri and Shalhevet, 1973; Chabbra, 1996; Munns, 2002b). It has been observed that plants do not wilt under salt stress at water potentials that are causing wilting under water stress and concluded that the detrimental effects of salinity are caused by a lack of water rather than too high salt levels (Francois, Grieve, Maas and Lesch, 1994). Plants grown with saline water have a significantly lower water uptake than those grown in fresh water (Chabbra, 1996). A strong linear relationship (r=0.97) between the electrical conductivity (EC) of the nutrient solution and plant water consumption has also been demonstrated by Chabbra (1996).

2.3.2 Hormones

The balance between root and shoot hormones changes considerably under saline conditions (Munns, 2002b). Salt stress reduces cytokinin production in the roots and its transport to the shoot (Munns, 2002b). The root supply of cytokinin to the leaves is essential for protein synthesis (Munns, 2002b). Therefore, the reduction in the supply of hormones to the leaves result in reduced transpiration and growth rate. The balance between root and shoot hormones may result in the osmotic effect on growth retardation and transpiration on the suppression under saline conditions (Chabbra, 1996; Munns, 2002b).

2.3.3 Damage to plant cells and cytoplasmic organelles

The accumulation of high levels of ions in plant leaves result in cell death and necrosis (Francois *et al.*, 1994). This is a result of changes in the structure of the chloroplast and mitochondria of leaves and these changes interfere with the plant's normal metabolism and growth (Munns, 2002b).

2.3.4 Interference with normal metabolism

Salinity increases respiration and reduces photosynthetic products available for growth (Cuartero and Munoz, 1999). The increase in respiration is the result of energy required for ion uptake and the reduction in photosynthesis is attributed to stomatal closure under saline conditions (Munns, 2002b).

2.4 Salt response during plant development

According to Rhoades and Loveday (1990), salt sensitivity changes considerably during the development of a plant. Three developmental stages can be distinguished with respect to salt tolerance or salt sensitivity: germination, vegetative growth and reproductive growth. Maas and Hoffman (1977) further indicated that the vegetative growth stage in crop species is particularly salt sensitive. A more complicated pattern arises for germination (Maas, 1990). Many plant species germinate readily in the presence of high concentrations of salt. The developmental shift in sensitivity and relative tolerance varies according to plant species and cultivars (Rhoades and Loveday 1990).

2.4.1 Germination

The study of salinity on germination is only relevant where direct sowing would result in poor germination and emergence, therefore jeopardise the economic viability of the crop (Cuartero and Munoz, 1999). According to Ayers and Westcot (1976) the effect of salinity on germinating seeds in many species is not only on lowering of the germination percentage, but also on lengthening the time needed to complete germination. According to Katerji, Van Hoorn, Hamdy, Karam and Mastrorilli (1996), the main effect of salt stress on germination seems to be in the prevention of seed water uptake from the soil in the first phase of germination, therefore, the process of imbibition is delayed (Maas and Poss, 1989; Van Hoorn, 1991).

2.4.2 Shoot development

Salinity inhibits shoot growth in plants at all developmental stages, for example high salinity at seedling stage will result in a lesser shoot growth (Chabbra, 1996; Szabolcs, 1989). Likewise the ability of plants to adapt to salinity seems to be higher in older than younger plants, because of sensitivity of new developing cells to saline conditions. Both stem and leaf dry weights are diminished in saline conditions due to the reduced rate of cell enlargement (Munns, 2002a).

A slower leaf growth results in a smaller transpiring area and lower water consumption, therefore, a lower transpiration rate (Chabbra, 1996). Thus, a decrease in leaf weight does not seem to be due to a reduction in the number of leaves but rather a reduction in leaf area, which in proportion is reduced more than the shoot dry weight (Hu *et al.,* 2000; Munns, 2002b). Katerji *et al*. (1996) also found that salinity had a greater effect on the development of leaf area and canopy dry matter of sunflower than that of maize. Furthermore, Maas and Hoffman (1977) also found that salinity and leaf area are usually inversely related and also established that the leaf growth and water consumption of plants grown under saline conditions were lower than that of plants grown under non-saline conditions.

Katerji, Van Hoorn, Hamdy, Bouzid, Mahrous and Mastrorilli (1992) also found a reduction in the shoot dry weight of broad beans as a result of salinity. Though faba beans showed similar reductions, the inhibitory effect of salt was only apparent after 4 weeks of growth (Cordovilla, Ligero and Lluch, 1999), furthermore the shoots appeared to be more sensitive than the roots. Not withstanding the fact that specific metabolic processes were inhibited, leaf growth rate was decreasing more than the rate of photosynthesis (Munns, 2002b).

2.4.3 Root development

Cuartero and Munoz (1999) stated that salt stress of the plant begins with the exposure of roots to a saline environment. It further leads to changes in the growth, morphology and physiology of roots that will in turn change water and ion uptake and the production of signals (hormones) that communicates information to the shoot. The whole plant is therefore affected when roots are growing in a salty medium (Chabbra, 1996). A lower root biomass is the consequence of the reduced root growth (Saqib *et al*., 2004b). Snapp and Shennan (1992), did not only observe a reduction in root growth in a saline medium, but also found roots to be longer under normal conditions.

According to Saqib *et al*. (2004b) both root length and density of wheat was significantly reduced by salinity. In spite of the negative effect of salt on the roots, root growth of many crops appeared to be less affected by salt than shoot growth (Cordovilla *et al*., 1999; Munns, 2002b). Cordovilla *et al*. (1999) also found that salinity significantly reduced root dry weight, nodule weight and mean nodule weight of faba beans.

2.5 Crop salt tolerance

Salinity is a widespread phenomenon on earth and the evolution of living organisms has resulted in numerous species that show special adaptive mechanisms to grow in a saline environment (Maas, 1986, Maas, 1990; Rhoades and Loveday, 1990). The majority of plants are relatively salt sensitive and almost all crops are unable to tolerate permanent saline conditions in the soil (Maas, 1986). Not withstanding this fact, a great deal of variation occurs between plants and this could be attributed to the salts involved, crop growth conditions, the age and variety of plants (Maas and Hoffman, 1977). Salt tolerance of plants not only varies considerably among species, but also depends heavily upon cultural as well as the interaction of soil, water, plant and environmental conditions under which the crop is grown (Chabbra, 1996).

Maas (1986, 1990) stated that the tolerance of a crop is based on: a) its ability to survive in saline soils, b) the reduction in growth and yield at different salinity levels, c) and its growth or yield when grown in saline soils compared to non-saline soils. The salt tolerance of a plant can be defined as the plant's capacity to endure the effects of excess salts in the growth medium. Generally plants respond similarly to salinity over a fairly wide range of combinations of salts. It has been reported that crops tolerated a higher degree of salt stress when prevailing weather conditions were cool and humid than hot and dry (Maas, 1990). For example, high temperature, low humidity and high wind increases evaporation and make the plant more susceptible to salinity (Maas, 1990).

Consequently the plant responses to known salt concentrations cannot be predicted on an absolute basis. Nevertheless, plants can be compared on a relative basis to provide general salt tolerance guidelines (Maas, 1990). It is well established that soil salinity does not reduce yield significantly until a threshold is exceeded as shown in Figure 2.1. Beyond this threshold, yield decreased almost linearly with an increase in salinity (Maas and Hoffman, 1977). To avoid yield loss when salt concentrations exceed the crop salt tolerance limit, excess salts must be leached below the root zone. According to Chabbra (1996), a higher concentration of individual ions in the root environment may prove to be toxic to the plant or may retard the uptake and metabolism of the essential plant nutrients and thus affect normal growth.

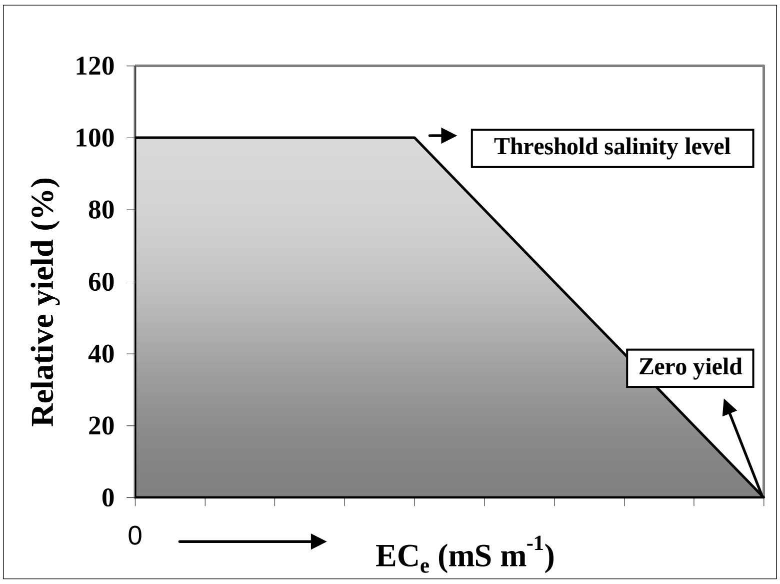


Figure 2.1 Hypothetical yield response of crops to increasing salinity (EC_e) on relative basis (adapted from Maas and Hoffman, 1977).

Maas and Hoffman (1977) published a comprehensive analysis based upon an extensive review of literature. Maas (1990), outlined that salt tolerances, must be defined in terms of yield reduction during growth or yield reduction caused by a specific concentration of salts, therefore the salt tolerances of many plants were expressed using the following equation:

$$Yr = 100 - b\,(EC_e - a) \qquad 2.1$$

where: Yr = percentage of the yield of the crop grown under saline conditions relative to that obtained under non-saline conditions,

a = threshold level of soil salinity at which yields start to decrease,

b = percentage yield loss per increase in salinity in excess of a,

EC_e = electrical conductivity of the saturation extract (mS m^{-1}).

Equation 2.1 assumes that crops respond primarily to the osmotic potential of the soil solution and the actual response to salinity varies with many factors including climate, soil conditions, agronomic practices, irrigation management, crop variety, stage of crop growth and salt composition (Maas, 1990). The majority of plants are relatively salt tolerant during germination and more sensitive during seedling emergence and early stages of growth

(Läuchli and Epstein, 1990). During these growth stages crops showed to differ in salt tolerance and therefore different classes of crop sensitivity have been established. Table 2.1 shows different classes of the selected crops of this study in bold.

Table 2.1 Salt tolerance of some agronomic crops. Crops used in this study are highlighted in bold (After Maas, 1986)

Common name	**Botanical name**	**Threshold mS m^{-1} (EC$_e$)**	**Slope % of mS m^{-1} (EC$_e$)**	**Rating**
Cotton	*Gossypium hirsutum*	770	5.2	T
Barley	*Hordeum vulgare*	800	5	T
Wheat	***Triticum aestivum***	**600**	**7.1**	**MT**
Cowpea	*Vigna unguiculata*	490	12	MT
Maize	***Zea mays***	**170**	**12**	**MS**
Peanut	*Arachis hypogea*	320	29	MS
Potato	*Solanum tuberosum*	170	12	MS
Bean	***Phaseolus vulgare***	**100**	**19**	**S**
Pea	***Pisum sativum***	**-**	**-**	**S**

* T = Tolerant, MT = Moderately Tolerant, MS = Moderately Sensitive, S = Sensitive

Figure 2.1 shows that yield response curves provide two essential parameters sufficient for expressing salt tolerance – the maximum allowable salinity without yield reduction for non saline conditions, and a slope – the percentage yield decrease per unit increase in salinity beyond the threshold (Maas, 1990). However, Maas (1990) documented that it is difficult to compare different crops, since yields of different crops are not expressed in comparable units. To eliminate this problem, yields can be expressed on a relative basis. Relative yield (Yr) is therefore defined as the yield of a crop grown under saline conditions as a fraction of that achieved under non-saline conditions, but otherwise comparable conditions (Maas, 1990).

Van Genuchten and Hoffman (1984) also proved that where a salinity hazard was to be encountered, the effective use of available soil and water resources dictated the production of agricultural crops. As a result numerous field and laboratory experiments have been conducted to determine the yield response of cultivated crops to different salinity levels. Van Genuchten and Hoffman (1984) came to the same conclusions as (Maas and Hoffman, 1977).

2.6 Factors influencing salt tolerance

Much research has been done to determine crop response to salinity by measuring crop yields at increasing salinity and relating yield reduction to soil salinity (Maas and Hoffman, 1977; Maas, 1986; Maas, 1990; Katerji *et al*., 1996). This method permits us to distinguish between salt tolerant and salt sensitive crops and to choose a cropping pattern corresponding with the expected salinity. The method is simple and practical, but it does not, however explain the behaviour of crops under non-saline conditions, nor why crops differ in salinity tolerance.

Maas (1990) reported that the plant's ability to tolerate salinity or specific ions is a function of many factors. A relative yield versus salinity response curve usefully expresses salt tolerance if a reduction in yield is independent of differences in actual yield resulting from differences in the conditions of the soil, properties of the soil, irrigation practices, climate, and other variables mentioned below (Maas, 1990; Rhoades and Loveday, 1990).

2.6.1 Soil fertility

In irrigated agriculture, fields are usually fertilised to achieve maximum productivity. Crops grown on soils with a low fertility level may seem more salt tolerant than those grown on soils of adequate fertility, because fertility and not salinity primarily limits the growth of plants (Maas and Hoffman, 1977). According to Maas (1990) similar effects were obtained with salinity and soil infertility with regard to yield limitation. Therefore, a decrease in salinity or by increasing soil fertility these yield limitations will be restricted. It has to be noted that soil fertility also interacts with salinity to affect the apparent tolerance of many crops.

2.6.2 Physical soil conditions

Soil characteristics can also affect the tolerance of crops (Maas and Hoffman, 1977). This was established in soils with a poor structure or impermeable layers that restricted root growth and influenced the distribution of water and salt in the soil (Maas and Hoffman, 1977). Poorly drained soils can also cause poor aeration of the soil, which may affect the plants response to salt stress (Maas, 1990). The fertility level may account for apparent differences in salinity tolerance (Maas and Hoffman, 1977) and poor physical soil conditions seriously impair root development and thus induce nutrient deficiencies (Shainberg and Oster, 1978).

2.6.3 Salt distribution in the profile

Soil salinity is seldom constant with time or uniform in space (Chabbra, 1996). Depending on the extent of leaching and drainage, salt distribution in the soil may be uniform in the soil but may change relatively with depth (Maas, 1990). The tolerance of plants to salt, therefore, should be related to salinity integrated over time and measured where roots absorb the largest volume of water in the root zone (Maas, 1990).

2.6.4 Irrigation methods

The salt tolerance of crops also depends on the type and frequency of irrigation (Chabbra, 1996). The salt concentration increases as the soil water content decreases between irrigations. Consequently, plants are exposed to increasing saline water with time between irrigations (Maas, 1990). The method of irrigation also affects the depth of irrigation, runoff, deep percolation losses, uniformity of application, and thereby salinity (Richards, 1954; Chabbra, 1996). Plants respond differently to saline waters, depending on the irrigation method used in the following ways (Yaron, 1973).

Under furrow or drip irrigation, salinity levels are low immediately beneath the water source and increases with depth (Chabbra, 1996). Sub surface irrigation provides no means of leaching the soil above the source of water and unless the soil is leached, salt will accumulate to toxic levels. Consequently, sprinklers often allow much efficient water use and a reduction in deep percolation. With this method, the lateral salt distribution is relatively uniform but soil salinity increase with depth (Yaron, 1973; Chabbra, 1996).

2.6.5 Climate

Climate probably influences the response of plants more than any other factor (Szabolcs, 1989; Maas, 1990). Most crops can tolerate higher levels of salt stress when the weather is cool and humid, than if it is hot and dry. Except for the coastal areas, saline soils are rarely found in humid regions because the salt is washed from the root zone by rain water (Chabbra, 1996) and therefore, salt affected soils are common in arid and semi-arid regions that receive inadequate and irregular precipitation (Szabolcs, 1989). The accumulation of salts in the surface layer can also be enhanced when a cool wet season alternates with a hot and dry season (Chabbra, 1996).

2.6.6 Stage of growth

The sensitivity of crops to salinity often changes from one stage of growth to the next (Francois *et al.*, 1994). Most plants are tolerant during germination but become sensitive during the stages of emergence and early seedling growth and plant stand can be seriously affected at this stage (Maas, 1990). However, according to Van Hoorn (1991) the localised high salt concentrations at seedling depth rather than specific sensitivity may be an immediate cause of germination failure. Salt stress may delay emergence, but does not influence the final emergence for most crops if the salt concentration remains at or below the tolerance threshold (Maas and Hoffman, 1977).

2.6.7 Varieties

Tolerance or plant sensitivity of varieties within species may differ significantly (Maas and Hoffman, 1977; Maas, 1990). Most of the commercially grown cultivars are developed under non saline conditions and not bred to endure salt stress. Therefore, the salt tolerance of most species are based on tests done on only a few cultivars, which are then used as a standard for classifying the crops (Maas, 1990).

2.7 Quantifying salinity diagnosis

Saline soils result in poor spotty growth of crops, uneven or stunted growth and poor yields (Abrol *et al.*, 1988). High soluble salts from over fertilisation cause rapid and severe salinity symptoms and this include wilted foliage and burning of tips and margins of leaves (Hu *et al.*, 2000). Plants may wilt during bright times of the day, even though the growth medium is moist. Overall plant growth will be inhibited, roots die from the tip backwards, particularly in the dryer zones of the growth medium and leaves become necrotic. These necrotic areas appear in some cases along the margin and in others as circular spots across the leaf blade (Abrol *et al*., 1988). Ultimately, many nutrient deficiency symptoms will occur as a result of acutely impaired nutrient uptake by the injured root system.

Chabbra (1996) emphasised that salinity conditions in the field can be identified through:

a) presence of a white crust of salt on the soil surface in a dry state;
b) high water tables, mostly within 2 meters of the soil surface with the subsoil usually being brackish and unfit for irrigation;
c) patchy and stunted crop growth, often with greenish to bluish colouration;

d) wilting, a sign of water stress in plants even when the soil apparently contains enough water. Generally a thin soil crust that may prevent emergence of seedlings of sensitive plants is present; and
e) natural vegetation consisting of small bushes and some salt tolerant species.

Salt stress frequently occurs under irrigation in the arid and semi-arid regions of South Africa. This results in poor seedling establishment, crop growth, reduced yields, financial losses and ultimately unsustainable crop production. Therefore, the response of the selected crops under saline conditions had to be evaluated and this prompted this study and the attempt to find answers.

2.8 REFERENCES

ABID, M., QAYYUM, A., DASTI, A.A. & WAJID, R.A., 2001. Effect of salinity and SAR of irrigation water on yield, physiological growth indicators of maize (*Zea mays* L.) and properties of the soil. *J. of Res. Sci.* (Pakistan) 12, 26-33.

ABROL, I.P., YADAV, J. S. & MASSOUD, F.I., 1988. Salt affected soils and their management. FAO Soils Bulletin 39, Rome.

ABU-AWWAD, A.M., 2001. Influence of different water quantities and qualities on lemon trees and soil salt distribution at the Jordan Valley. *Water Manage.* 52, 53-71.

AKHTAR, J., GORHAM, J. & QURESHI, R.H., 1994. Combined effect of salinity and hypoxia in wheat (*Triticum aestivum* L.) and wheat-Thinopyrum amphiploids. *Plant Soil* 166, 47-54.

AYERS, R.S. & WESTCOT, D.W., 1976. Water quality for agriculture. FAO Irrigation and drainage paper 29, Rome.

BACKEBERG, G.R., BEMBRIDGE, T.J., BENNIE, A.T.P., GROENEWALD, J.A., HAMMES, P.S., PULLEN, R.A. & THOMPSON, H., 1996. Policy proposal for irrigated agriculture in South Africa. Water Research Commission Report KV 96/96, Pretoria.

BRESLER, E., MCNEAL, B.L. & CATER, D.L., 1982. Saline and sodic soils: Principles-Dynamics-Modelling. Advanced agricultural series 10. Springer Verlag, Germany.

CHABBRA, R., 1996. Soil salinity and water quality. Balkema Publishers. Brookfield, Missouri.

CORDOVILLA, M.D.P., LIGERO, F. & LLUCH, C., 1999. Effect of salinity on growth, nodulation and N assimilation in nodules of faba bean (*Vicia faba* L.). *Appl. Soil Ecol*. 11, 1-7.

CUARTERO, J. & MUNOZ, R.F., 1999. Tomato and salinity. *Sci. Hort.* 78, 83-125.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY., 1996. South African water quality guidelines, 2nd ed. Volume 4. Agricultural use: Irrigation. Government Printer, Pretoria.

DU PREEZ, C.C., STRYDOM, M.G., LE ROUX, P.A.L., PRETORIOUS, J.P., VAN RENSBURG, L.D. & BENNIE, A.T.P., 2000. Effect of water quality on irrigation farming along the lower Vaal River: The influence on soils and crops. Water Research Commission Report No: 740/1/00, Pretoria.

FIREMAN, M. & KRAUS, M., 1965. Salinity control in irrigated agriculture. Tahal, Israel.

FRANCOIS, L.E., GRIEVE, C.M., MAAS, E.V. & LESCH, S.C., 1994. Time of salt stress affect growth and yield components of irrigated wheat. *Agron. J.* 86, 100-107.

FRENKEL, H., 1984. Reassessment of water quality criteria for irrigation. In Shainberg, I. & Shalhevet, J. (eds). Soil Salinity under Irrigation-Processes and Management: Ecological Studies 51. Springer Verlag Berlin Heideberg, Germany.

FRENKEL, H. & MEIRI, A., 1985. Soil salinity: Two decades of research in irrigated agriculture. Van Nostrand Reinhold Company Inc., New York.

GHASSEMI, F., JAKEMAN, A.J. & NIX, H.A., 1995. Salinisation of land and water resources: Human causes, Extent, Management & Case Studies. University of South Wales Press, Australia.

HALL, A. E., 2001. Crop responses to Environment. CRC Press, Boca Raton, Florida.

HEROLD, C.E. & BAILEY, A.K., 1996. Long term salt balance of the Vaalharts irrigation scheme. WRC report 420/1/96, Pretoria.

HU, Y., CAMP, K.H. & SCHIMDHALTER, U., 2000. Kinetics and spatial distribution of leaf elongation of wheat (*Triticum aestivum* L.) under saline conditions. *Int. J. Plant Sci.* 161, 575-582.

KATERJI, N., VAN HOORN, J.W., HAMDY, A., BOUZID, N., MAHROUS, S. & MASTRORILLI., 1992. Effect of salinity on water stress, growth and yield of broadbeans. *Agric. Water Manage.* 21, 107-117.

KATERJI, N., VAN HOORN, J. W., HAMDY, A., KARAM, F. & MASTRORILLI, M., 1996. Effect of water stress, growth, and yield of maize and sunflower. *Agric. Water Manage*. 30, 237-249.

LÄUCHLI, A. & EPSTEIN, E., 1990. Plant responses to saline sodic conditions. In K.K. Tanji (ed). Agricultural salinity assessment and management. Am Soc. of Civ. Eng., New York.

LYNCH, J., POLITO, V.S. & LÄUCHLI, A., 1989. Salinity stress increases cytoplasmic Ca in maize root protoplasts. *Plant Physiol.* 90, 1271-1274.

MAAS, E.V., 1986. Salt tolerance of plants. *Appl. Agric. Res*. 1, 12-26.

MAAS, E.V., 1990. Crop salt tolerance. In K.K Tanji (ed). Agricultural salinity assessment and management. Am. Soc. of Civ. Eng., New York.

MAAS, E. V. & HOFFMAN, G. J., 1977. Crop salt tolerance: Evaluation of existing data. In E. H. Dregne (ed). Managing saline water for irrigation. Proceedings of the international salinity conference, Texas.

MAAS, E.V. & POSS, J.A., 1989. Salt sensitivity of wheat at various growth stages. *Irrig. Sci*. 10, 29-40.

MEIRI, A. & LEVY, R., 1973. Evaluation of salinity in soils and plants. In B. Yaron, E. Danfors, Y. Vaadia (eds). Arid zone irrigation: Ecological Studies 5. Springer-Verlag Berlin, Germany.

MEIRI, A. & SHALHEVET, J., 1973. Crop growth under saline conditions. In B. Yaron, E. Danfors, Y. Vaadia (eds). Arid zone irrigation: Ecological Studies 5. Springer-Verlag Berlin, Germany.

MUNNS, R., 2002a. Comparative physiology of salt and water stress. *Plant, Cell Env.* 25, 239-250.

MUNNS, R., 2002b. The impact of salinity stress. CSIRO division of plant industry, Australia. http://www.plantstress.com/Aricles/index.asp

RAMOLIYA, P.J. & PANDEY, A., 2001. Effect of salinization of soil on emergence, growth and survival of seedling of *Cordia rothii*. *For. Ecol. Manage*. 176, 185-194.

RHOADES, J.D. & LOVEDAY, J., 1990. Salinity in irrigated agriculture. In A.B. Steward & D.R, Nielsen (eds). Irrigation of agricultural crops. Agron. Soc. of Am., Madison, Wisconsin.

RICHARDS, L.A., 1954. Diagnosis and improvement of saline and alkali soils. Government Printing Office, Washington.

RUSSELL, E.W., 1973. Soil conditions and plant growth, 10^{th} ed. Longman Inc., London.

SAIRAM, R.K., RAO, K.V. & SRIVASTAVA, G.C., 2002. Differential response of wheat genotypes to long term salinity stress in relation to oxidative stress, antioxidant activity and osmolyte concentration. *Plant Sci*. 163, 1037-1046.

SAQIB, M., AKHTAR, J. & QURESHI, R.H., 2004a. Pot study on wheat growth in saline and waterlogged compacted soil I. Grain yield and yield components. *Soil Tillage Res*. 77, 169-177.

SAQIB, M., AKHTAR, J. & QURESHI, R.H., 2004b. Pot study on wheat growth in saline and waterlogged compacted soil I. Root growth and leaf ionic relations. *Soil Tillage Res*. 77, 179-187.

SHAINBERG, I. & OSTER, D., 1978. Quality of irrigation water. International Irrigation information centre: Publication no: 2, Israel**.**

SHAINBERG, I. & SHALHEVET, J., 1984. Soil salinity under irrigation: Processes and management. Springer – Verlag Berlin Heideberg, Germany.

SNAPP, S.S. & SHENNAN, C., 1992. Effects of salinity on root growth and death dynamics of tomato. *New Phytologist* 121, 71-79.

SZABOLCS, I., 1986. Agronomical and ecological impact on soil and water salinity. *Adv. Soil. Sci*. 4, 189-218.

SZABOLCS, I., 1989. Salt-affected soils. CRC Press, Baco Raton, Florida.

TALSMA, T. & PHILIP, J.R., 1971. Salinity and water use: National symposium on hydrology. Macmillian Press, London.

TANJI, K.K., 1990. Nature and extent of agricultural salinity. In K.K. Tanji (ed). Agricultural salinity assessment and management. Am. Soc. of Civ. Eng., New York.

VAN GENUCHTEN, M. & HOFFMAN, G.J., 1984. Analysis of crop salt tolerance data. In I. Shainberg & J. Shalhevet (eds). Soil salinity under irrigation-processes and management: Ecological Studies 51. Springer Verlag, Germany.

VAN HOORN, J.W., 1991. Development of soil salinity during germination and early seedling growth and its effect on several crops. *Agric. Water Manage*. 20, 17-28.

YARON, B., 1973. Water suitability for irrigation. In B. Yaron, E. Danfors, Y. Vaadia (eds). Arid zone irrigation: Ecological Studies 5. Springer-Verlag Berlin, Germany.

CHAPTER 3

WHEAT *(Triticum aestivum* L.*)* GROWTH AND YIELD RESPONSE TO SALINE IRRIGATION WATER UNDER CONTROLLED CONDITIONS

3.1 ABSTRACT

Salinisation (an increase in the concentration of total dissolved salts in both soil and water) has lead to serious agronomic problems where water was mainly used for irrigation. The effect of irrigation water salinity on wheat was investigated, where electrical conductivity (EC_i, mS m^{-1}) was used as the salinity indicator. A pot experiment was conducted, at the University of the Free State during 2003 (Y1) and 2004 (Y2), to determine the effect of the differing EC_i levels on germination, growth, and yield of wheat (cv. SST 806) on a sandy loam soil. A complete randomised design with a factorial combination consisting of two main factors, *viz*. five EC_i levels (15-control, 150, 300, 450, 600 mS m^{-1}), three stages (tillering, flag leaf and maturity) replicated thrice were conducted during two growing seasons. A laboratory study on germination was also conducted and this study has shown that varying levels of salinity (EC_i) did not significantly affect germination, coleoptile length and root length. However, the results showed a decrease in all indicators measured with an increase in EC_i. Various morphological indicators were used to quantify the impact of EC_i on the below ground growth of wheat, *viz.* root mass and root length. For above ground mainly plant height and leaf area index were used. Indicators were sampled at tillering, flag leaf and maturity stages. All indicators expressed on a relative basis showed a decrease in growth in relation to an increase in the EC_i. The analysis indicated that the below ground growth was more sensitive to salinity than the above ground growth. However, the final analysis on the yield confirmed the concerns of farmers who experienced yield losses due to salinity. The results indicated that the process of grain filling was adversely affected, especially the individual seed mass as indicated by 100 seed mass.

3.2 INTRODUCTION

South Africa, compared to the rest of the world, is a small producer of wheat and has to import wheat annually to meet its domestic consumption requirements. Wheat is also the second most important field crop grown in South Africa for a variety of purposes and together with secondary processing industries provides a large number of job opportunities. The wheat production has approximately 3 800 to 4 000 commercial wheat growers, providing work opportunities to about 28 000 people (National Department of Agriculture - NDA, 2003). During 2000 to 2004, approximately 2.2 million ton of wheat was annually produced (NDA, 2005). The production of irrigated wheat cannot be excluded and therefore the important contribution of irrigation areas and the sustainability of irrigation schemes have to be insured, especially with regard to the quality of irrigation water used.

The greatest threat for sustainable crop production under irrigation is the use of irrigation water with a deteriorating quality. Globally large areas of land are available for wheat production in the arid and semi-arid regions, but much of this land has the constraint of actual or potential salinity (Chabbra, 1996). The unreliability and variability of rainfall in these areas makes irrigation a vital component of the agricultural industry globally, but also in South Africa (Backeberg, Bembridge, Bennie, Groenewald, Hammes, Pullen and Thompson, 1996) and accordingly agriculture, especially irrigation farming, is currently the largest consumer of available water in South Africa (Department of Water Affairs and Forestry - DWAF, 1996).

Salinity seriously constrain crop yield in irrigated agriculture throughout the world (Cordovilla, Ligero and Lluch, 1999). Moreover, the continuous global depletion of good-quality fresh water resources and the ever increasing water demand is making the use of saline water inevitable for agriculture (Fireman and Kraus, 1965). Realising this, it is important to know that water management and quality are intimately related to the development of salinity posing a threat to sustainable crop production. The composition of dissolved constituents in water determines its quality for irrigation use, hence the quality of irrigation water is an important consideration in any appraisal of salinity conditions in an irrigated area (Richards, 1954; Szabolcs, 1989). Worldwide irrigation fields tend to become less productive as a result of salt accumulation, making the soil less suitable for crop production (Ayers and Westcot, 1976). Therefore, water quality may become a more important factor than quantity in some areas of the country and crop selection has to be considered.

Salinity resistance in plants (crops) is usually quantified in terms of surviving rate and or growth abilities in stress conditions (Chabbra, 1996). To establish the suitability of plants for saline agriculture, it is essential to study its response to differing salinity levels (Abid, Qayyum, Dasti and Wajid, 2001). Excessive salt in the root zone adversely affects germination, leaf growth, total biomass accumulation and ultimately crop yield (Chabbra, 1996; Cuartero and Munoz, 1999; Abid *et al.,* 2001; Saqib, Akhtar and Qureshi, 2004a, b). This also shows that all plant growth stages are affected by saline conditions. Typical visual symptoms observed under these conditions are reduced vegetation, scorched leaf tips or margins, abscission of leaves and premature discolouration. Below ground symptoms are underdeveloped root systems and it may also appear to be discoloured. These symptoms are mainly the result of accumulated salts reducing the plant’s ability to take up water, thus an osmotic effect (Abrol, Yadav and Massoud, 1988; Maas, 1990; Ghassemi, Jakeman and Nix, 1995).

Many farmers are utilising irrigation water without considering its water quality and its effects, as a result they experience unacceptable yield reductions (Du Preez, Strydom, Le Roux, Pretorius, Van Rensburg and Bennie, 2000). Therefore, the objective of the study was to quantify the effect of saline irrigation water (EC_i levels) on the germination, growth (at different growth stages) and yield of wheat (*Triticum aestivum* L.).

3.3 MATERIALS and METHODS

Two experiments were conducted to achieve the objective *viz*. a germination experiment executed in the laboratory and a glasshouse pot experiment for determining the effect of salinity on growth and yield components.

3.3.1 Irrigation water solution

Five irrigation water quality treatments were used. In order to prepare these treatments, sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium sulphate ($MgSO_4$), sodium sulphate (Na_2SO_4), potassium chloride (KCl) and magnesium chloride ($MgCl_2$) were used. The ratios and combination of salts to obtain the required electrical conductivity (EC) and sodium adsorption ratio (SAR) values were established through experimentation in the laboratory. The total dissolved salts (TDS) values were theoretically calculated by the following equation:

$$TDS\ (mg\ \ell^{-1}) = EC\ (mS\ m^{-1})\ x\ 6.5 \qquad 3.1$$

This relationship was proposed by the DWAF (1996). The electrical conductivity (EC_i) and sodium adsorption ratio (SAR) of the irrigation water that was used is presented in Table 3.1.

Table 3.1 The electrical conductivity (EC_i, mS m^{-1}), sodium adsorption ratio (SAR) and amount of different salts to prepare the required irrigation water quality treatments

	EC_i (mS m^{-1})			
	150	**300**	**450**	**600**
SAR	3	5	5	5
TDS (mg ℓ^{-1})	988	2003	3554	5107
NaCl (mg ℓ^{-1})	360	790	1140	1415
$CaCl_2$ (mg ℓ^{-1})	100	235	500	825
$MgSO_4$ (mg ℓ^{-1})	297	620	1190	1740
Na_2SO_4 (mg ℓ^{-1})	0	50	20	45
KCl (mg ℓ^{-1})	105	187	533	750
$MgCl_2$ (mg ℓ^{-1})	45	40	90	250
Ca: Mg	1:1.31	1:1.31	1:1.32	1:1.31
Ca: Cl	1:1.33	1:1.32	1:1.33	1:1.32

The ratios of calcium (Ca^{2+}) to magnesium (Mg^{2+}) (1.2 to 1.6) and sulphate (SO_4^{2-}) to chloride (Cl^-) (1.3 to 1.4) were based on the values obtained from long term values of the lower Vaal and Riet Rivers (Du Preez *et al.*, 2000).

3.3.2 Germination experiment

The germination experiment consisted of five different saline water qualities *viz*. 15 (control), 150, 300, 450 and 600 mS m^{-1}. The Anchor-germination paper method was used and fifteen wheat seeds were evenly distributed on a pencil line 100 mm from the top of the Anchor-germination paper. Another paper was placed on top and wetted with 50 ml of the specific treatment water. The germination papers were rolled and separately inserted into 1 ℓ Erlenmeyer flasks. Five replicates were used. To prevent dehydration of the germination paper the top of each was covered with a small polyethylene bag followed by incubation at a temperature of 25^0C. Three days after initiation of the experiment, the first observations were made with 24 hour intervals over five days. During this period, germination percentage (%), coleoptile length (mm) and root length (mm) were measured. Only results obtained on the last recording date will be presented.

3.3.3 Glasshouse pot experiment

Asbestos pots (0.34 x 0.34 x 0.35 m) with a volume of 40.5 ℓ were used. A gravel layer approximately 30 mm thick (5 kg) was placed at the bottom of each pot to facilitate drainage. A cloth was placed on the gravel layer separating the soil and the gravel to prevent the soil from penetrating the gravel and blocking the drainage tube. Each pot was filled with 70 kg of a red sandy loam Bainsvlei top soil (particle size distribution: coarse sand 10.3%, medium sand 6.4%, fine sand 83.3%, silt 2.0% and clay 8%) after the soil was dried and sieved through a 2 mm sieve. The pots were leached with 25 ℓ of the specified water quality to create the target salinity level before planting. Five salt concentrations *viz*. 15 (control), 150, 300, 450 and 600 mS m^{-1} were used (section 3.3.1). The level of fertiliser application was based on soil analysis from samples collected before filling the pots. Three days after leaching, fertilisers were uniformly applied to the equivalent of 82 kg N, 41 kg P, and 20 kg K ha^{-1} and incorporated to a depth of 100 mm. A topdressing to the equivalent of 103.5 kg of N ha^{-1} was applied four weeks after emergence (wae). After planting the outlets of the pots were closed and no leaching was allowed. The pots (individually) were watered manually by hand using the same volume of water per event. At the end of the experiment each pot received 140 ℓ during year 1 (Y1) and 145 ℓ during year 2 (Y2) for the respective growing seasons until the plants reached maturity. This high volume of water could be ascribed to the fact that the plants were confined to a small volume of soil relative to the canopy. Wheat (cv. SST 806) was planted during July 2003 (Y1) and June 2004 (Y2) in three rows, 100 mm apart representing a sowing rate of 120 kg seeds ha^{-1} and grown in the glasshouse at day/night temperatures of $20/10^0$C. The experiment was laid out in a completely randomised design with a factorial combination consisting of two main factors, *viz*. five EC_i levels, as mentioned, and three growth stages (tillering, flag leaf and maturity), replicated thrice and conducted over two seasons.

The following indicators were used to evaluate the influence of the saline water on wheat growth and yield on a relative basis: plant height (mm plant^{-1}), leaf area index (m^{2} m^{-2}), number of tillers, root mass (g m^{-2}), root length (mm roots mm^{-2} of soil surface), total above-ground biomass, referred to as biomass (g m^{-2}), number of ears, seed yield (g m^{-2}), seed mass ear^{-1}(g), and 100 seed weight (g). Leaf area was measured using the LICOR 3000 leaf area meter and leaf blade of wheat without sheath were sampled and. Roots were washed from the pots through a 0.5 mm sieve. The length of the roots were determined with a modified infrared root line intersection counter as described by Rowse and Phillips (1974). The root mass was obtained by weighing after drying at 60^{0}C for 72 hours. The biomass (all plants per pot) was obtained through weighing the harvested produce after it had been dried. Seed yield was obtained by weighing the harvested seeds after drying to a constant mass.

The experimental data were analysed with the NCSS (Number Cruncher Statistical System) statistical package (Hintze, 1998). The least significant difference (LSD) was calculated at $P \leq 0.05$ to compare the means using the Tukey-Kramer multiple-comparison test (Gomez and Gomez, 1984). Though the experiment was a complete randomised design with a factorial combination, the different sampling stages were analysed separately as it was expected that significant differences would occur between growth stages as a result of continued growth.

3.4 RESULTS and DISCUSSION

3.4.1 Germination percentage, coleoptile and root length

Germination and seedling growth are two indispensable indicators for the establishment of a crop (Richards, 1954), because failure during this phase will be reflected in the potential and actual yield (Van Hoorn, 1991; Chabbra, 1996). According to Maas and Poss (1989) and Van Hoorn (1991) a delay in germination under saline conditions may also be attributed to a reduced rate of water uptake, particularly during imbibition. No significant reduction in germination percentage was obtained with the selected range of EC_i levels (Table 3.2). This corresponds with other research and wheat is therefore, rightfully classified as moderately tolerant with regard to germination (Maas and Hoffman, 1977; Maas, 1990). Germination percentage only reflects on the quantity aspects and not the quality of seedling establishment. It was argued that both the coleoptile length and root length would reflect the quality of seedlings. Interesting results were obtained on this aspect, with both indicators showing a continuous decrease in length with an increase in the EC_i level and this agrees with the observation of Shirazi, Asif, Khanzada, Khan, Ali, Muntaz, Yosufzai and Saif (2001). However, the expansion of both the coleoptile and root length showed no significant reduction compared to the control. Rhoades and Loveday (1990) showed that emerged seedlings could also die if seedling roots were exposed to saline conditions.

Table 3.2 Effect of different EC_i levels on germination percentage, coleoptile and root length of wheat

Plant indicators	**Treatments (mS m^{-1})**					
	15*	150	300	450	600	LSD $_{(0.05)}$
Germination (%)	100	99	97	99	100	ns
Coleoptile length (mm)	150	145	147	128	136	ns
Root length (mm)	112	109	108	103	98	ns

* = Control.

ns = not significant.

3.4.2 Response of wheat at tillering, flag leaf and maturity

The statistical results of all the above ground and below ground plant indicators are presented in Table 3.3. Apparently it seems as if the growing condition was slightly better during Y2 as all the maximum indicators of Y2 were slightly higher than that of Y1. This could be ascribed to a longer growing season (1 month) during the second season. However, when expressing the resulting growth indicators relative to its maximum response of a particular season, the main indicators showed no significant differences in its response to seasons. Therefore, the relative data of Y1 and Y2 were combined in the regression and statistical analysis for all growth stages (Table 3.3).

3.4.2.1 Below ground plant response

As indicated in Table 3.3, two indicators were selected for characterising the below ground response to irrigation water salinity, *viz.* root length index and root mass. Both indicators are regarded as highly variable in space and time (Van Antwerpen, 1988; Bennie, Van Rensburg, Strydom and Du Preez, 1997) as also can be seen in the great variation between the two years over the growth stages for the maximum response obtained with the well watered control of

Y1 and Y2. Surprisingly, the mean root length per unit soil surface area corresponds well with the mean sampled by Bennie, Coetzee, Van Antwerpen, Van Rensburg and Burger (1988) from 42 well watered (irrigation) farm plots located in the central part of South Africa. The means of the experiment are 4.6, 6.1, and 6.6 mm mm^{-2} for tillering, flag leaf and maturity stages, respectively, while the mean of the farm plots amounted to 4.2, 5.22 and 5.38 mm mm^{-2} at similar stages. This proves that the plants were well watered in the pots as many researchers found a direct response of root length and mass to crop water stress and hence, water availability. Salinisation also impact directly on root length and mass, as can be seen from the regression lines depicted on a relative scale for various growth stages in Figure 3.1. Significant reductions (Table 3.3) in both indicators were obtained at an EC_i of 300 mS m^{-1} and higher except for root mass at maturity (150 mS m^{-1}). This reduction in root growth and length at different growth stages over the selected EC_i range are supported by the results obtained by Saqib *et al*. (2004b).

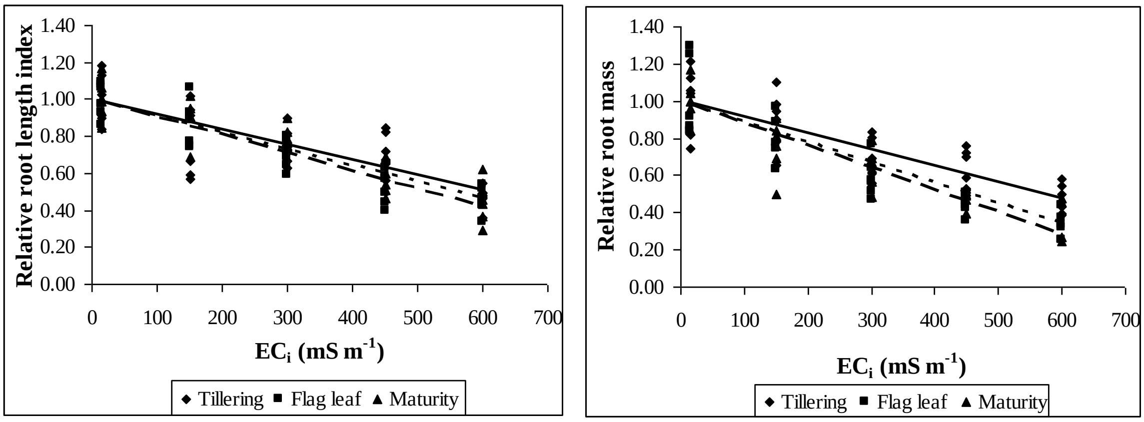


Figure 3.1 The effect of differing EC_i levels (irrigation water salinity) on root length and root mass at different stages of growth (tillering, flag leaf and maturity are represented by a solid, dashed and dotted line, respectively).

The reduction in root mass and length was slightly lower at tillering compared to later growth stages. This could be ascribed to the accumulation of salts in the soil as a result of continued irrigation to support plant growth in the closed system. Excess salinity in the root zone adversely affected the growth of established plants by a reduction in cell size as well as the rate of cell production (Kurth, Cramer, Läuchli and Epstein, 1986; Rhoades and Loveday, 1990). This was probably caused by the total soil water potential due to the increase in osmotic component of the soil water. Therefore, salinisation often causes shorter and thicker roots (Zidan, Azaizeh and Neumann, 1990; Azaizeh, Gunse and Steudle, 1992). The pot experiment shows that the root mass is slightly more sensitive than the root length at all growth stages (Figure 3.1). Salinisation reduces the soil volume that could be explored by the roots and hence the availability and uptake of water (Maas and Nieman, 1997).

Table 3.3 Statistical results of the response of wheat at tillering, flag leaf and maturity to saline irrigation water as indicated by various plant indicators on a relative scale

Plant indicators	Maximum response			Regression coefficients			PR (%)		PSD	
	Unit	Y1	Y2	intercept	Slope	r^2	300	600	(mS m^{-1})	LSD $_{(0.05)}$
Tillering										
Below ground										
Root mass	(g m^{-2})	78	88	1	-0.0009	0.69	27	54	300	0.25
Root length index	(mm mm^{-2})	3.45	5.82	1	-0.0008	0.59	24	48	300	0.13
Above ground										
Number of tillers	(m^{-2})	1058	1028	1	-0.0005	0.73	15	30	300	0.12
Plant height	(mm $plant^{-1}$)	520	553	1	-0.0008	0.8	24	48	150	0.08
Leaf area index	(m^2 m^{-2})	7.5	8.4	1	-0.0006	0.65	18	36	300	0.18
Biomass	(g m^{-2})	345	399	1	-0.0007	0.84	21	42	300	0.13
Flag leaf										
Below ground										
Root mass	(g m^{-2})	135	169	1	-0.0012	0.78	36	72	300	0.24
Root length index	(mm mm^{-2})	4.67	7.43	1	-0.001	0.84	30	60	300	0.17
Above ground										
Number of tillers	(m^{-2})	894	870	1	-0.0005	0.73	15	30	300	0.13
Plant height	(mm $plant^{-1}$)	564	608	1	-0.0007	0.81	21	42	150	0.09
Leaf area index	(m^2 m^{-2})	11.54	13.05	1	-0.0006	0.55	18	36	300	0.2
Biomass	(g m^{-2})	658	698	1	-0.0005	0.8	15	30	300	0.1
Maturity										
Below ground										
Root mass	(g m^{-2})	197	193	1	-0.0011	0.78	33	66	150	0.13
Root length index	(mm mm^{-2})	5.14	8.01	1	-0.0009	0.81	27	54	300	0.17
Above ground										
Plant height	(mm $plant^{-1}$)	763	813	1	-0.0003	0.65	9	18	300	0.08
Number of ears	(m^{-2})	597	652	1	-0.0003	0.36	9	18	450	0.11
Seed mass	(g ear^{-1})	1.46	1.45	1	-0.0004	0.52	12	24	600	0.16
100 seed mass	(g)	3.88	3.61	1	-0.0005	0.74	15	30	450	0.11
Biomass	(g)	1751	1812	1	-0.0004	0.83	12	24	300	0.07
Seed yield	(g)	886	939	1	-0.0006	0.82	18	36	300	0.11

PR = Percentage reduction observed over the EC range estimated with the linear regression equation at 300 and 600 mS m^{-1} and subtracted from the control.

PSD = Point of statistical difference in relation to the control.

Maximum response = Response obtained by the control plants.

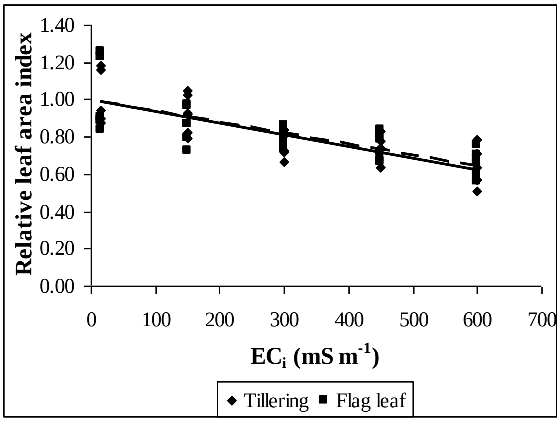
3.4.2.2 Above ground plant response

Plant height and leaf area are all practical above ground agronomical indicators for comparing the plant response to any opposed stress, provided that a control is available. The non-water and non-salinity-stress control revealed that the canopy generally experienced better growth than the roots, because it is not confined to a specific volume as the roots in the pots. Prove for this can be seen from the mean leaf area of the control at various growth stages, which were almost twice that reported by Bennie *et al.* (1997).

Even the number of tillers were about 20% more than that obtained by Bennie *et al.* (1997) under a weekly irrigation regime. This explains the unusual high water uptake when expressed in mm per unit area for the pots in comparison to the irrigated fields. In natural fields the aerial parts of the plant compete for space within and between rows, while in the pot experiment this is not fully the case. Despite this phenomenon, it is still possible to characterise the effect of irrigation water salinity on above ground indicators by comparing the EC_i treatments relative to the control. The regression statistical data is available in Table 3.3 and the trendlines plotted in Figure 3.2 for plant height and leaf area. From the negative slopes of the regression lines it is evident that salinity affected both plant indicators at all growth stages as found by Akthar, Gorham And Qureshi (1994), Abid *et al*. (2001) and Saqib *et al*. (2004a, b) for plant height and for leaf area by Maas and Hoffman (1997).

Plant height at both the tillering and flag leaf stages were significantly reduced at an EC_i of 150 mS m^{-1}. This reduction was more severe during the tillering stage (12%) than the later growth stages (10.5%). Though not as severe, the reduction in plant height was also significant at maturity with a reduction of only 9% at 300 mS m^{-1}, compared to 24% and 21% at the tillering and flag leaf growth stages, respectively. The reduction in plant height is probably caused by reduction in cell elongation, which ultimately restricted the growth rate (Van Hoorn, Katerji, Hamdy and Mastrorilli, 1993; Francois, Grieve, Maas and Lesch, 1994; Lutts, Almansouri and Kinet, 2004). It also has to be noted that plant height could be used as an effective visual measure to evaluate the intensity of salinity since it was the most sensitive above ground plant indicator, with the greatest slopes at the tillering and flag leaf growth stages.

Leaf area at both the tillering and flag leaf growth stages were significantly reduced (18%) at an EC_i 300 mS m^{-1}, compared to the leaf area obtained with the control. According to the slopes both these growth stages showed the same degree of sensitivity to salinity for leaf area. Salinity during the early vegetative growth stage and later stages has been shown to decrease leaf number in wheat, therefore reducing the leaf area (Francois *et al*., 1994). A reduction in leaf area results in lesser light interception, thus leading to reduced canopy growth. By comparing the slopes, it can be derived that leaf growth (area) was affected less than root growth (length and mass) and this was in contrast with what was found in literature. Leaf growth is often reduced more than root growth (Munns, 2002a; Munn, 2002b) and it was also established that the growth of younger leaves was inhibited by salinity due to a reduction in the supply of carbohydrates to the growing cells. This could be the result of reduced stomatal conductance and thus photosynthesis, resulting in reduced production of photosynthates and eventually leaf area (Munns, 2002a). The production of new leaves depend largely on the water potential of the soil solution as affected by salts (Munns, 2002a) and similar results were obtained during drought stress (Chabbra, 1996). It was found that leaf width and length was reduced by salinity and leaf appearance was also delayed. This largely determines the rate of plant growth (Hu, Camp and Schimdhalter, 2000).



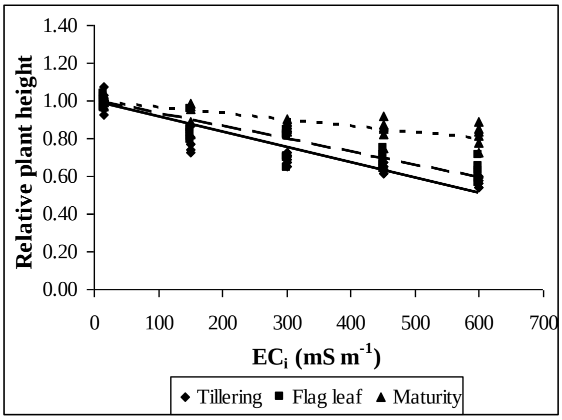


Figure 3.2 The effect of differing EC_i levels (irrigation water salinity) on leaf area and plant height at different stages of growth (tillering, flag leaf and maturity are represented by a solid, dashed and dotted line, respectively).

3.4.2.3 Yield and yield components

Following the argument made on the huge difference between the actual maximum crop response for the above ground indicators for the pot versus the field experiments, this discussion will focus from the onset on the relative yield as affected by the saline irrigation water (Figure 3.3). As expected, the lines suggested that the biomass is negatively affected by an increase in the EC_i at all growth stages. Table 3.3 also indicated that the tillering stage was the most sensitive to salinity, with regard to biomass, followed by flag leaf and then maturity stage. From these trends it can be derived that the plants have adapted to the salinity conditions over time.

It is expected that the soil water salinity would have increased over time, since leaching was not allowed during the experiment (Chapter 6). The tiller number is normally well related to the biomass yield as it is an essential component of the yield. Tiller number in this study was significantly reduced (15%) at an EC_i of 300 mS m^{-1} at both the tillering and flag leaf stages (Table 3.3). Maas and Hoffman (1977), Maas and Poss (1989), Akhtar *et al*. (1994), Francois *et al*. (1994) and Saqib *et al.* (2004a) ascribed the severe reduction in tiller number during the early growth stages to a higher degree of sensitivity during the early growth stages of wheat. This phenomenon was further supported by the findings of Maas, Lesch, Francois and Grieve (1994), stating that the development and viability of primary and secondary tillers are greatly influenced by salinity, drought and other environmental stresses. It also has to be noted that the number of tillers was less for the control at the flag leaf stage than at the tillering stage. This reduction could be attributed to the abscission of tillers with the progress in plant development. Salt stress during tiller emergence could also inhibit their formation and cause an increased rate of abortion at later stages (Maas *et al*., 1994; El-Hendawy, Hu, Yakout, Awad, Hafiz and Schmidhalter, 2005).

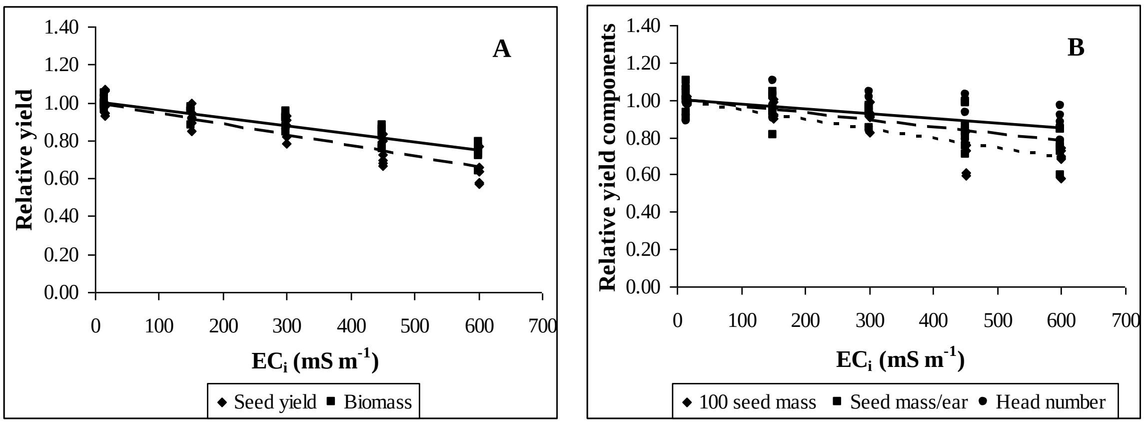


Figure 3.3 The effect of differing EC_i levels (irrigation water salinity) on biomass, seed yield and yield components at maturity [biomass and seed yield are represented by a solid and a dashed line (A), whereas head number, seed mass ear^{-1} and 100 seed mass are represented by a solid, dashed and dotted line, respectively (B)].

The relative yield graphs as shown in Figure 3.3 suggested that salinity affected the seed yield more than the biomass. From the regression coefficient and statistical results it can be calculated that the seed yield was significantly reduced by 18% at an EC_i level of 300 mS m^{-1} and by 36% at 600 mS m^{-1}, compared to the control. This trend was the result of the accumulated reduction obtained for all the yield components (Figure 3.3) in response to an increase in the EC_i. This is also supported by the findings of Sairam, Rao and Srivastava (2002), Singh, Minhas, Chauhan and Gupta (1992), Steppuhn, Volkmar and Miller (2001) and Saqib *et al*. (2004a).

The yield components of wheat were significantly reduced at maturity at an EC_i of 450 mS m^{-1} for the number of ears and 100 seed mass, but seed mass ear^{-1} was only significantly reduced at an EC_i of 600 mS m^{-1}. Comparing the percentage reduction of different yield components at 300 mS m^{-1}, the highest reduction was obtained for100 seed mass (15 %), followed by seed mass ear^{-1} (12 %) and number of ears (9 %) (Figure 3.3). These typical response differences to salinity was also observed by Francois *et al.* (1986), Akhtar *et al*. (1994), Francois *et al.* (1994), Maas *et al*. (1996) and Katerji, Van Hoorn, Fares, Hamdy, Mastrorilli and Oweis (2005). They also reported that the yield components, which includes number of ears, number of spikelets, floret fertility, and individual kernel weight, were all significantly reduced as a result of an increase in salinity.

According to Munns, Husain, Rivelli, James, Condon,, Lindsay, Lagudah, Schachtman and Hare (2002) and Poustini and Siosemardeh (2004) growth reduction in a high salinity substrate is the result of a water deficit or ion imbalances and/or ion toxicity (Saqib *et al*., 2004a; Parida and Das, 2005) that ultimately result in a reduced yield. Furthermore, salinity affects the formation and viability of reproductive organs in annuals (cereals) by reducing the number of florets per ear, altering the time of flowering and hence the ultimate yield at maturity (Maas *et al*., 1996; El-hendawy *et al.*, 2005).

According to Munns and Rawson (1999) this corresponds with the response of crops subjected to drought stress. It has been proven that the reduction in yield is highly correlated with the reduction of tiller number per plant (Maas and Poss, 1989; Maas *et al*., 1994; Hu *et al.*, 2000; Shirazi *et al*., 2001). The lower ultimate yield obtained is not only the result of the reduction in the number of tillers per plant due to increased salinity, but also the grain size and seed weight. It was also established that grain yield was reduced as a result of a severe reduction in 100 seed mass (Poustini and Siosemardeh, 2004) also reported this. In the present study the quality of grain was not evaluated but according to Francois *et al.* (1986) the grain quality of wheat could also be significantly affected by salinity.

3.5 CONCLUSIONS

The germination experiment confirmed that wheat can be regarded as moderately sensitive to salt stress. None of the indicators (percentage seedlings germinated, coleoptile length and root length) showed a significant reduction over the EC_i range from 15 to 600 mS m^{-1}. It should be mentioned that the quality of the seedlings declined over the range of EC_i values used and expected to be significantly reduced at a slightly higher than the maximum EC_i value applied in the present study.

Interesting results were obtained in the glasshouse pot experiment with regard to the sensitivity of the below and above ground growth of wheat to EC_i (15 to 600 mS m^{-1}) at tillering, flag leaf and maturity growth stages. It was observed that the below ground growth, as indicated by root length index and root mass, were more affected than the above ground indicators (leaf area index and plant height). This phenomenon was ascribed to the rapid rate of salt accumulation in the pots, as leaching was not allowed during the growing season. Despite this, the plants used a luxurious amount of water, which stimulated canopy growth in relation to the pot area. The leaf area index, for example the control (non water or salt stress treatment) was 2 times higher than that expected under field conditions. This was attributed to the absence of field plant competition in the canopy zone. Despite this, the relative growth analysis showed that the EC_i impacted negatively on the measured parameters in all growth stages. Both the biomass and seed yield were negatively influenced by EC_i. From the yield components it was concluded that seed filling was probably mostly affected, as the 100 seed mass was found to be most sensitive. The seed yield was significantly reduced by 18% at an EC_i of 300 mS m^{-1} and by 36% at 600 mS m^{-1}.

3.6 REFERENCES

ABID, M., QAYYUM, A., DASTI, A.A. & WAJID, R.A., 2001. Effect of salinity and SAR of irrigation water on yield, physiological growth indicators of maize (*Zea mays L.*) and properties of the soil. *J. of Res. Sci.* (Pakistan) 12, 26-33.

ABROL, I.P., YADAV, J.S. & MASSOUD, F.I., 1988. Salt affected soils and their management. FAO Soils bulletin 39, Rome.

AKHTAR, J., GORHAM, J. & QURESHI, R.H., 1994. Combined effect of salinity and hypoxia in wheat (*Triticum aestivum L.)* and wheat-Thinopyrum amphiploids. *Plant and Soil* 166, 47-54.

AYERS, R.S. & WESTCOT, D.W., 1976. Water quality for agriculture. FAO Irrigation and drainage paper 29, Rome.

AZAIZEH, H., GUNSE, B. & STEUDLE, E., 1992. Effect of NaCl and $CaCl_2$ on water transport across root cells of maize (*Zea mayz* L.) seedlings. *Plant Physiol.* 99, 886-894.

BACKEBERG, G.R., BEMBRIDGE, T.J., BENNIE, A.T.P., GROENEWALD, J.A., HAMMES, P.S., PULLEN, R.A. & THOMPSON, H., 1996. Policy proposal for irrigated agriculture in South Africa. Water Research Commission Report KV 96/96, Pretoria.

BENNIE, A.T.P., COETZEE, M.J., VAN ANTWERPEN, R., VAN RENSBURG, L.D. & BURGER, R., 1988. ’n Waterbalansmodel vir besproeiing gebasseer op profiel watervoorsienings-tempo en gewaswaterbehoeftes. Water Research Commission Report no 144/1/88, Pretoria.

BENNIE, A.T.P., VAN RENSBURG, L.D., STRYDOM, M.G. & DU PREEZ, C.C., 1997. Reaksie van gewasse op voorafgeprogrammeerde tekortbesproeiing. Water Research Commission Report no 423/1/97, Pretoria.

CHABBRA, R., 1996. Soil salinity and water quality. Balkema Publishers. Brookfield, Missouri.

CORDOVILLA, M.D.P., LIGERO, F. & LLUCH, C., 1999. Effect of salinity on growth, nodulation and N assimilation in nodules of faba bean (*Vicia faba* L.). *Appl. Soil Ecol*. 11, 1-7.

CUARTERO, J. & MUNOZ, R.F., 1999. Tomato and salinity. *Sci. Hort.* 78, 83-125.

DU PREEZ, C.C., STRYDOM, M.G., LE ROUX, P.A.L., PRETORIUS, J.P., VAN RENSBURG, L.D. & BENNIE, A.T.P., 2000. Effect of water quality on irrigation farming along the lower Vaal River: The influence on soils and crops. Water Research Commission Report No: 740/1/00, Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1996. South African water quality guidelines 2nd edition: Volume 4. Agricultural use: Irrigation. Government Printer, Pretoria.

EL-HENDAWY, S.E., HU, Y., YAKOUT, G.M., AWAD, A.M., HAFIZ, S.E. & SCHMIDHALTER, U., 2005. Evaluating salt tolerance of wheat genotypes using multiple parameters. *Eur. J. Agron.* 22, 243-253.

FIREMAN, M. & KRAUS, M., 1965. Salinity control in irrigated agriculture. Tahal, Israel.

FRANCOIS, L.E., GRIEVE, C.M., MAAS, E.V. & LESCH, S.C., 1994. Time of salt stress affect growth and yield components of irrigated wheat. *Agron. J.* 86, 100-107.

FRANCOIS, L.E., MAAS, E.V., DONOVAN, T.J. & YOUNGS, V.L., 1986. Effect of salinity on grain yield and quality, vegetative growth, and germination of semi dwarf and durum wheat. *Agron. J.* 78, 1053-1058.

GHASSEMI, F., JAKEMAN, A.J. & NIX, H.A., 1995. Salinisation of land and water resources: Human causes, extent, management & case studies. University of South Wales Press, Australia.

GOMEZ, K.A. & GOMEZ, A.A., 1984. Statistical procedures for agricultural research, 2nd edition. John Wiley & Sons Inc, New York.

HINTZE, J.L., 1998. Number cruncher statistical systems (NCSS 2000). Kaysville, Utah.

HU, Y., CAMP, K.H. & SCHIMDHALTER, U., 2000. Kinetics and spatial distribution of leaf elongation of wheat (*Triticum aestivum* L.) under saline conditions. *Int. J. Plant Sci.* 161, 575-582.

KATERJI, N., VAN HOORN, J.W., FARES, C., HAMDY, A., MASTRORILLI, M. & OWEIS, T., 2005. Salinity effect on grain quality of two durum wheat varieties differing in salt tolerance. *Agric. Water Manage.* 75, 85-91.

KURTH, EVA, CRAMER, G.R., LÄUCHLI, A. & EPSTEIN, E., 1986. Effect of NaCl and $CaCl_2$ on cell enlargement and cell production in cotton. *Plant Physiol.* 82, 1102-1106.

LUTTS, S., ALMANSOURI, M. & KINET. J. M., 2004. Salinity and water stress have contrasting effects on the relationship between growth and cell viability during and after stress exposure in durum wheat callus. *Plant Sci.* 167, 9-18.

MAAS, E.V., 1990. Crop salt tolerance. In K.K. Tanji (ed). Agricultural salinity assessment and management. Am. Soc. of Civ. Eng., New York.

MAAS, E.V. & HOFFMAN, G.J., 1977. Crop Salt Tolerance: Evaluation of existing data. In E. H. Dregne (ed). Managing saline water for irrigation. Proceedings of the International Salinity Conference, Texas.

MAAS, E.V., LESCH, S.M., FRANCOIS, L. E. & GRIEVE, C.M., 1994. Tiller development in salt-stressed wheat. *Crop Sci.* 34, 1594-1963.

MAAS, E.V., LESCH, S.M., FRANCOIS, L.E. & GRIEVE, C.M., 1996. Contribution of individual culms to yield of salt-stressed wheat. *Crop Sci*. 36, 142-149.

MAAS, E.V. & NIEMAN, R.H., 1977. Physiology of plant tolerance to salinity. In crop tolerance to suboptimal land conditions. ASA, Madison, Wisconsin.

MAAS, E.V. & POSS, J.A., 1989. Salt sensitivity of wheat at various growth stages. *Irrig. Sci*. 10, 29-40.

MUNNS, R., 2002a. Comparative physiology of salt and water stress. *Plant, Cell Environ.* 25, 239-250.

MUNNS, R., 2002b. The impact of salinity stress. CSIRO division of plant industry, Australia. http://www.plantstress.com/Aricles/index.asp

MUNNS, R., HUSAIN, S., RIVELLI, A.R., JAMES, R.A., CONDON, A.G., LINDSAY, M.P., LAGUDAH, E.S., SCHACHTMAN, D.P. & HARE, R.A., 2002. Avenues for increasing salt tolerance of crops, and the role of physiologically based selection traits. *Plant and Soil* 247, 93-105.

MUNNS, R. & RAWSON, H.M., 1999. Effect of salinity on salt accumulation and reproductive development in the apical meristem of wheat and barley. *Aus. J. of Plant Physiol.* 26, 459 – 464.

NATIONAL DEPARTMENT OF AGRICULTURE, 2003. Maize production. Directorate of agricultural information, Pretoria.

NATIONAL DEPARTMENT OF AGRICULTURE, 2005. Agricultural statistics, Pretoria.

PARIDA, A.K. & DAS, A.B., 2005. Salt tolerance and salinity effects on plants: a review. *Ecotox. Environ*. 60, 324-349.

POUSTINI, K. & SIOSEMARDEH, A., 2004. Ion distribution in wheat cultivars in response to salinity stress. *Field Crop Res*. 85, 125-133.

RICHARDS, L.A., 1954. Diagnosis and improvement of saline and alkali soils. Government Printing Office, Washington.

RHOADES, J.D. & LOVEDAY, J., 1990. Salinity in irrigated agriculture. In A.B. Steward & D.R. Nielsen (eds). Irrigation of agricultural crops. Agron. Soc. of Am., Madison, Wisconsin.

ROWSE, H.R. & PHILLIPS, D.A., 1974. An instrument for estimating the total length of root in a sample. *J. Appl. Ecol.* 11, 309-314.

SAIRAM, R.K., RAO, K.V. & SRIVASTAVA, G.C., 2002. Differential response of wheat genotypes to long term salinity stress in relation to oxidative stress, antioxidant activity and osmolyte concentration. *Plant Sci*. 163, 1037-1046**.**

SAQIB, M., AKHTAR, J. & QURESHI, R.H., 2004a. Pot study on wheat growth in saline and waterlogged compacted soil I. Grain yield and yield components. *Soil Til. Res*. 77, 169-177.

SAQIB, M., AKHTAR, J. & QURESHI, R.H., 2004b. Pot study on wheat growth in saline and waterlogged compacted soil II. Root growth and leaf ionic relations. *Soil Till Res*. 77, 179-187.

SHIRAZI, M.U., ASIF, S.M., KHANZADA, B., KHAN, M.A., ALI, M., MUNTAZ, S., YOSUFZAI, M.N. & SAIF, M., 2001. Growth and ion accumulation in some wheat genotypes under NaCl stress. *Pak. J. of Biol. Sci.* 4, 388-391.

SINGH, R.B., MINHAS, P.S., CHAUHAN, C.P.S. & GUPTA, R.K., 1992. Effect of high salinity and SAR waters on salinisation, sodication and yields of pearl-millet and wheat. *Agric. Water Manage.* 21, 93-105.

STEPPUHN, K., VOLKMAR, K.M. & MILLER, P.R., 2001. Comparing canola, field pea, dry bean, and durum wheat crops grown in saline media. *Crop Sci.* 41, 1827-1833.

SZABOLCS, I., 1989. Salt-affected soils. CRC Press, Baco Raton, Florida.

VAN ANTWERPEN, R., 1988. Evaluasie van verskillende empirise modelle vir die voorspelling van wortel groei. M.Sc.Agric. Thesis, University of the Free State, Bloemfontein.

VAN HOORN, J.W., 1991. Development of soil salinity during germination and early seedling growth and its effect on several crops. *Agric. Water Manage*. 20, 17-28.

VAN HOORN, J.W., KATERJI, N., HAMDY, A. & MASTRORILLI, M., 1993. Effect of saline water on soil salinity and on water stress, growth, and yield of wheat and potatoes. *Agric. Water. Manage*. 23, 247-265.

ZIDAN, I., AZAIZEH, H. & NEUMANN, P.M., 1990. Does salinity reduce growth in maize root epidermal cells by inhibiting their capacity for cell wall acidification? *Plant Physiol.* 93, 7-11.

CHAPTER 4

MAIZE (*Zea mays* L.) GROWTH RESPONSE TO SALINE IRRIGATION WATER UNDER CONTROLLED CONDITIONS

4.1 ABSTRACT

The effect of irrigation water salinity on maize was investigated, where electrical conductivity (EC_i, mS m^{-1}) was used as a salinity indicator. A pot experiment was conducted, at the University of the Free State from February 2004 (Y1) and again from November 2004 (Y2) to determine the effect of the differing EC_i levels on germination and growth of maize (cv. PNR 6335) on a sandy loam soil. A complete randomised design with a factorial combination consisting of two main factors, *viz*. five EC_i levels (15-control, 150, 300, 450, 600) and three growth stages [2 wae (wae - weeks after emergence), 4 wae and 6 wae] replicated thrice were conducted during two growing seasons. A laboratory experiment on germination was also conducted and this study has shown that varying levels of salinity (EC_i) did not significantly affect germination, but both coleoptile length and root length were significantly affected. The results of this study showed that all indicators decreased as a result of increasing EC_i levels. Various morphological indicators were used to quantify the impact of EC_i on the below ground growth of maize, *viz.* root mass and root length. For above ground leaf area, leaf number, plant height, stem diameter and biomass were used. All indicators were sampled at 2 wae, 4 wae and 6 wae. All indicators expressed on a relative basis showed a decrease in growth in relation to an increase in the EC_i. Though the analysis indicated all indicators were significantly affected at varying degrees as a result of increasing EC_i levels of the irrigation water, no difference in sensitivity between below and above ground indicators were established. This study confirmed that an increase in the salinity of irrigation water had a negative effect on plant growth.

4.2 INTRODUCTION

Maize is the most important grain crop in South Africa and is produced throughout the country under diverse environments. Approximately 8 million tons of maize are produced under dry land and irrigation in South Africa annually on approximately 3.1 million ha (National Department of Agriculture, 2003). Maize is relatively sensitive to saline irrigation water, showing a 50% reduction in yield at an EC_i of 390 mS m^{-1} (Ayers and Westcot, 1976; Maas and Hoffman, 1977). The sensitivity of maize to salinity is emphasized with more than one report stating that maize is also more sensitive at early growth stages, but could withstand saline irrigation at later growth stages (Ayers and Westcot, 1976; Maas and Hoffman, 1977; Maas, 1990; Abid, Qayyum, Dasti and Wajid, 2001).

Sustainable agriculture in arid and semi-arid regions is mainly dependent on the availability of good quality irrigation water (Abid *et al.*, 2001). Good quality water in these areas is gradually becoming limited to meet the crop water requirements. In order to augment the inadequate water supplies, the use of inferior poor quality (saline) water is imperative. Globally, water quality is becoming a more important factor than quantity. Unfortunately, the major portion of water is not fit for irrigation due to variable amounts of impurities (Richards, 1954).

Continuous use of poor quality (saline) water could induce salinisation of soils and greatly hamper the growth of most field crops (Richards, 1954, Maas and Hoffman; 1977; Shainberg and Oster, 1978; Cordovilla, Ligero and Lluch, 1999; Abid *et al.*, 2001). The unreliability and variability of rainfall makes irrigation a vital component of agricultural industry in South Africa (Backeberg, Bembridge, Bennie, Groenewald, Hammes, Pullen and Thompson**,** 1996) and accordingly agriculture, especially irrigation farming, is currently the largest consumer of available water in South Africa (Department of Water Affairs and Forestry, 1996).

Excessive salt in the root zone adversely affect plants at different growth stages (Bernstein, 1975; Saqib, Akhtar and Qureshi, 2004). These adverse effects are reflected in decreased germination (Chabbra, 1996), leaf area (Cuartero and Munoz, 1999) and ultimately dry matter accumulation (Munns, 2002a). The mentioned adverse effects are the result of a reduction of plant’s ability to take up water and this is referred to as the osmotic effect of salinity (Abrol, Yadav and Massoud, 1988; Maas, 1990; Ghassemi, Jakeman and Nix, 1995).

Many farmers are using irrigation water without considering water quality and its effects and as a result they suffer unacceptable yield losses (Du Preez, Strydom, Le Roux, Pretorius, Van Rensburg and Bennie, 2000). Therefore, the objective of the study was to quantify the effect of saline irrigation water (EC_i levels) on the germination and early growth of maize (*Zea mays* L.).

4.3 MATERIALS and METHODS

Two experiments were conducted to achieve the objective *viz*. a germination experiment executed in the laboratory and a glasshouse pot experiment for determining the effect of salinity on the growth of maize.

4.3.1 Irrigation water solution

The irrigation water solutions used for this experiment were the same as that used for the wheat experiment. The preparation and composition of the different saline irrigation water treatments are given in Section 3.3.1.

4.3.2 Germination experiment

The laboratory germination experiment used is described in Section 3.3.2.

4.3.3 Glasshouse pot experiment

This study was conducted in the same asbestos pots described earlier and details can be found in Section 3.3.3. However, the level of fertiliser application was adapted to the equivalent of 217 kg N, and 49 kg P ha^{-1} and incorporated to a depth of 100 mm. The pots were watered by hand, using the same volume of water per event for each pot individually. At the end of the experiment each pot received 54 ℓ of water. The applied volume of water was the same for the respective growing seasons that continued for 6 weeks after emergence. The reason for growing maize for six weeks was based on findings of a study on maize during 1996 (Ceronio, 1997). Maize (cv. PNR 6335) was planted during February 2004 (Y1) and November 2004 (Y2) and thinned to three plants per pot and grown in the glasshouse at day/night temperatures of $25/15^0$C. The experiment was laid out in a completely randomised design with a factorial combination, consisting of two main factors as mentioned, *viz*. five EC_i levels as described and three growth stages (2 wae, 4wae and 6 wae), replicated thrice and conducted over two seasons.

The indicators used to evaluate the influence of the saline water on maize growth on a relative basis were: leaf area (cm^2 $plant^{-1}$), leaf number ($plant^{-1}$), stem diameter (mm $plant^{-1}$), plant height (mm $plant^{-1}$), root length index (mm mm^{-2} of soil surface), root mass (g $plant^{-1}$) and total above-ground biomass, referred to as biomass (g $plant^{-1}$). Leaf area was measured using the LICOR 3000 leaf area meter and leaf blade of maize without sheath were sampled. Plant height was measured by a ruler 10 mm from the soil surface up to a natural highest point. Stem diameter was measured by using a pair of callipers. Number of leaves were visually counted. The experimental data were analysed as described in Section 3.3.3.

4.4 RESULTS and DISCUSSION

4.4.1 Germination percentage, coleoptile and root length

Germination plays an indispensable role in crop establishment and failure will impact heavily on crop stand and ultimately yield (Rhichards, 1954; Chabbra, 1996). This is of the utmost importance, because it was established that emerged seedlings could also die if seedling roots were exposed to salinity conditions (Rhoades and Loveday, 1990). No significant reduction in germination percentage was obtained with the selected range of EC_i levels (Table 4.1). This corresponds with findings by Maas and Hoffman (1977) and Maas (1990), categorising maize as moderately sensitive to salinity at germination and sensitive during the early seedling growth stage.

Table 4.1 Effect of different EC_i levels on germination percentage, coleoptile and root length of maize

Plant indicators	**Treatments (mS m^{-1})**					
	15*	150	300	450	600	LSD $_{(0.05)}$
Germination (%)	98a	98a	97a	97a	97a	ns
Coleoptile length (mm)	149a	135a	113b	117b	110b	16.80
Root length (mm)	182a	170a	160a	137b	133b	29.69

* = Control.

ns = not significant.

It is important to note that germination percentage only reflects on the quantity aspects and not the quality of seedlings. Therefore, coleoptile and the root length were used to qualitatively evaluate the growth during germination. Surprisingly, both indicators showed a significant decrease in length with an increase in the EC_i level, which agrees with findings by Shirazi, Asif, Khahzada, Ali, Muntaz, Yosufzai and Saif (2001). The coleoptile length was significantly reduced by 12% at 300 mS m^{-1} and the root length by 25% at 450 mS m^{-1}. The rate of the expansion of these indicators was greatly inhibited over the increasing EC_i range, which could affect the establishment of the plants (Chabbra, 1996). The importance of evaluating the quality aspects of the seedlings is manifested in seedling establishment. A delay in germination under saline conditions may be attributed to a reduced rate of water uptake, particularly during the initial stages of the germination process (Maas and Poss, 1989).

4.4.2 Response of maize at different periods during the vegetative stage

The statistical results of all the above ground and below ground plant indicators are presented in Table 4.2. Apparently it seems as if the growing condition was slightly better in Y2 as all the maximum indicators of Y2 were slightly higher than that of Y1. This could be ascribed to seasonal variation where maize was planted at an optimum planting date in November. Although the glasshouse temperature was set at 25/15oC day/night regime, the outside temperature constantly increased with longer days which is exactly the opposite of what the plants experienced when planted in February. However, when expressing the resulting growth indicators relative to its maximum response of a particular season, indicators showed no significant differences in its response to seasons. Therefore, the relative data of Y1 and Y2 were combined in the regression and statistical analysis for all growth stages (Table 4.2).

4.4.2.1 Below ground plant response

As indicated in Table 4.2, two indicators were selected for characterising the below ground response to irrigation water salinity, *viz.* root length index and root mass. According to Van Antwerpen (1988) and Bennie, Van Rensburg, Strydom and Du Preez (1997) root length and root mass of maize are spatially highly variable. This was confirmed by the data over the growth stages for the maximum response with the well watered control of Y1 and Y2 (Table 4.2). With the exception of root length at 6 wae, change in the mean root length per unit soil surface compares well with the means sampled by Bennie, Coetzee, Van Antwerpen, Van Rensburg and Burger (1988) from 22 well watered farm plots. Plot means were 1.16, 3.93 and 6.07 mm mm^{-2} for 2, 4 and 6 wae, respectively, while the means of the pot experiment were respectively, 0.40, 3.34 and 14.27 mm mm^{-2} at similar stages. This proves that the plants were not subjected to water stress at any time, as many researchers found a direct response between root length and mass and crop water stress.

Table 4.2 Statistical results of the response of maize at two weeks, four weeks and six weeks after emergence to saline irrigation water by various plant indicators on a relative scale

Plant indicators	Maximum response			Regression coefficients			PR (%)		PSD	
	Unit	Y1	Y2	intercept	slope	r^2	300	600	(mS m^{-1})	$LSD_{(0.05)}$
2 wae										
Below ground										
Root mass	(g $plant^{-1}$)	0.24	0.55	1	-0.0013	0.46	39	78	450	0.60
Root length index	(mm mm^{-2})	0.15	0.66	1	-0.0014	0.57	41	82	300	0.35
Above ground										
Leaf number	(plant $^{-1}$)	6	6	1	-0.001	0.79	30	60	300	0.2
Leaf area	(cm^2 $plant^{-1}$)	99	102	1	-0.0019	0.91	57	100[a]	300	0.2
Plant height	(mm $plant^{-1}$)	353	331	1	-0.0014	0.81	41	82	300	0.19
Stem diameter	(mm $plant^{-1}$)	8.49	10.36	1	-0.0014	0.86	41	82	300	0.18
Biomass	(g $plant^{-1}$)	0.35	0.58	1	-0.0017	0.67	51	100[b]	300	0.48
4 wae										
Below ground										
Root mass	(g $plant^{-1}$)	3.7	6.7	1	-0.0016	0.73	48	96	300	0.29
Root length index	(mm mm^{-2})	1.48	5.2	1	-0.0014	0.70	41	82	300	0.23
Above ground										
Leaf number	(plant $^{-1}$)	9	10	1	-0.0014	0.81	41	82	300	0.23
Leaf area	(cm^2 $plant^{-1}$)	1710	1776	1	-0.0019	0.88	57	100[a]	300	0.34
Plant height	(mm $plant^{-1}$)	828	970	1	-0.0016	0.91	48	96	150	0.18
Stem diameter	(mm $plant^{-1}$)	20.81	23.54	1	-0.0015	0.87	45	90	300	0.20
Biomass	(g $plant^{-1}$)	11.84	13.49	1	-0.0019	0.88	57	100[a]	150	0.15
6 wae										
Below ground										
Root mass	(g $plant^{-1}$)	17.25	17.63	1	-0.0017	0.88	51	100[b]	150	0.15
Root length index	(mm mm^{-2})	10.81	17.73	1	-0.0016	0.84	48	96	150	0.15
Above ground										
Leaf number	(plant $^{-1}$)	12	12	1	-0.001	0.54	30	60	450	0.38
Leaf area	(cm^2 $plant^{-1}$)	4270	4903	1	-0.0017	0.81	51	100[b]	300	0.34
Plant height	(mm $plant^{-1}$)	1222	1458	1	-0.0013	0.82	39	78	300	0.2
Stem diameter	(mm $plant^{-1}$)	28.47	27.87	1	-0.0011	0.64	33	66	450	0.24
Biomass	(g $plant^{-1}$)	34.18	36.58	1	-0.0017	0.95	51	100[b]	150	0.12

PR = Percentage reduction observed over the EC_i range estimated with the linear regression equation at 300 and 600 mS m^{-1} and subtracted from the control.
PSD = Point of statistical difference in relation to the control.
a = 100% reduction at 530 mS m^{-1}.
b = 100% reduction at 590 mS m^{-1}.
Maximum response = Response obtained by the control plants.

A significant reduction in the below ground plant indicators were observed at 300 mS m^{-1} and higher, with the exception of both indicators at 6 wae, which were significantly affected at 150 mS m^{-1}. The higher degree of sensitivity at 6 wae could be ascribed to the accumulation of salts in the root zone with continued irrigation. The reduction in both below ground indicators was comparable for each stage. Irrigation with saline water directly affected both below ground indicators, as can be seen from the regression line depicted on a relative scale for various growth stages (Figure 4.1). Salinity in the root zone adversely affected the growth of established plants by a general reduction in growth rate, which lead to a reduced root length (Rhoades and Loveday, 1990; Chabbra, 1996). The reduction in root growth as a result of salinity was also observed by Lynch, Cramer and Läuchli (1987) and Saqib *et al*. (2004). They also found that salinity induced some morphological and structural changes that resulted in poor root elongation.

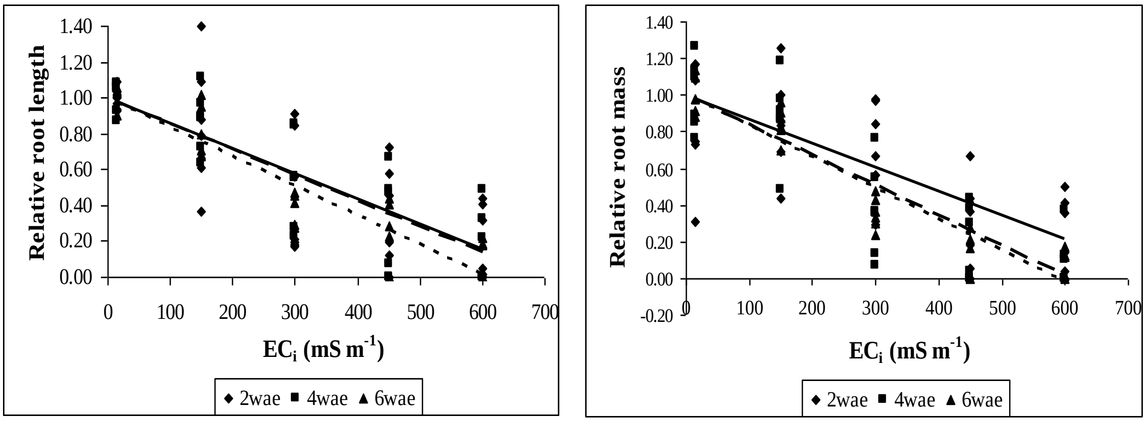


Figure 4.1 The effect of differing EC$_i$ levels (irrigation water salinity) on root length and root mass at different stages growth (2, 4 and 6 wae are represented by a solid, dashed and dotted line, respectively).

4.4.2.2 Above ground plant response

Plant height, stem diameter, leaf area and biomass are above ground agronomic indicators for comparing the plant response to any opposed stress, provided that a control is available. It is evident that salinity affected plant height at all growth stages (Table 4.2) and this correspond to the findings by Maas, Hoffman, Chaba, Poss and Shannon (1983) and Abid *et al*. (2001). Reduction in plant height was greater at 4 wae when compared to the other stages. Plant height was significantly reduced at 300 mS m^{-1} (41%), 150 mS m^{-1} (24%) and 300 mS m^{-1} (39%) at 2 wae, 4wae and 6wae, respectively. At 300 mS m^{-1} plant height at 4 wae was reduced by 48%. Negative slopes of the regression lines indicated that salinity affected measured plant indicators at all growth stages. The overall reduction in plant height could be ascribed to the osmotic effect of saline irrigation water that reduced the growth rate of the plants (Katerji, Van Hoorn, Hamdy and Mastrorilli, 2004) and also the uptake, transport and utilisation of different nutrients required for growth being disturbed by salinity (Saqib *et al.*, 2004).

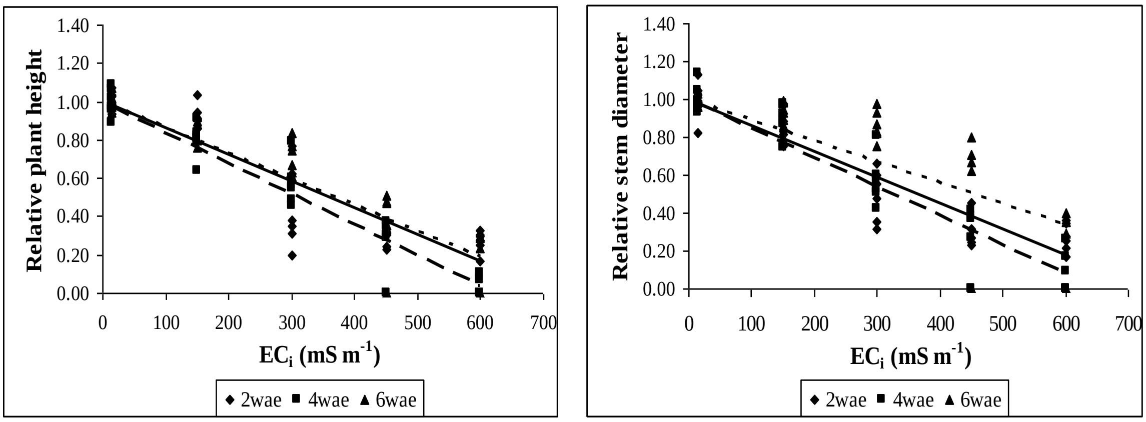


Figure 4.2 The effect of differing EC_i levels (irrigation water salinity) on plant height and stem diameter at different stages growth (2, 4 and 6 wae are represented by a solid, dashed and dotted line, respectively).

Stem diameter was severely reduced at 4 wae (90%) when compared to 2 wae (82%) and 6 wae (66%) at an EC_i of 600 mS m^{-1}. A reduction in growth rate as a result of an increase in EC_i levels of the irrigation water, significantly affected the stem diameter. Significant reductions were observed at 300 mS m^{-1} for both 2 wae and 4 wae and 450 mS m^{-1} for 6 wae. This could be ascribed to the reduction in the growth and expansion of stem cells due to the increased salinity of the soil, thus disturbing the plant metabolism (Abid *et al.*, 2001; Munns, 2002a). Irrigation with saline water directly affected both plant height and stem diameter as can be seen from the regression lines depicted on a relative scale for various growth stages (Figure 4.2). Number of leaves was also counted for all stages (Table 4.2). According to Aldrich and Leng (1966) two maize leaves unfold on average on a weekly basis under normal growth and development, thus one leaf every 3 – 4 days. If this is true the number of leaves at 2, 4 and 6 wae should be 4, 6 and 12 leaves respectively. Comparing this with the results obtained by the control plants (Table 4.2), it is clear that growth and development was not affected by increased salinity. It was found that the relative leaf number was significantly reduced at 300 mS m^{-1} for both 2 wae and 4 wae and at 450 mS m^{-1} for the 6 wae period. Therefore, this indicator can be used in practice to determine if the growth and development has either been stimulated or inhibited by the selected EC_i range, provided that a control is available. Comparing the rate of leaf appearance to the norm, it could be concluded that plant development was inhibited by salinity at early growth stages with an increase in the EC_i of the irrigation water.

In general, the reduction in leaf number significantly affected the ultimate leaf area of the plants, leading to a reduced biomass (Table 4.2). This correspond with the findings of Maas and Hoffman (1977), Bar-tal, Feigenbaum and Sparks (1991), Karterji, Van Hoon, Hamdy, Karam and Mastrorilli (1996), Abid *et al.,* (2001) and Yazar, Gencel and Sezen, (2003). The reduction in biomass could also be ascribed to a reduction in leaf size resulting in a lesser light interception leading to a reduced total leaf area. Leaf area was significantly reduced at 300 mS m^{-1} for all stages. Severe reductions were obtained at 2 and 4 wae (57%) and at 6 wae (51%) at an EC_i of 300 mS m^{-1}. Surprisingly, leaf area at all stages was reduced by 100% at EC_i levels beyond 530 mS m^{-1}. This indicated that saline irrigation water affected the plants entire growth, leading to a reduced biomass yield or even the death of plants. This is ascribed to the fact that leaf development largely determines the rate of plant growth, therefore, leaf count can be used as a guideline to monitor the growth and development of maize plants (Aldrich and Leng, 1966; Hu, Camp and Schimdhalter, 2000; Yazar *et al.*, 2003). Saline irrigation water directly affected both leaf area and biomass yield, as can be seen from the regression line depicted on a relative scale for various growth stages (Figure 4.3). According to Maas and Hoffman (1977) and Maas (1990) the maize plant is most sensitive to soil salinity during the seedling stage. Though this was not measured, the reduction in biomass production was higher at 4 wae (57%) than both 2 and 6 wae (51%) at 300 mS m^{-1}, respectively. The reduction in biomass as a result of increasing EC_i levels could be ascribed to the accumulation of elements reaching toxic levels within the plant and/or the osmotic effect reducing leaf area as a result of a reduction in growth. This concurs with other research work elsewhere (Maas *et al*., 1983; Lynch, Polito and Läuchli, 1989; Frenkel, Mantell, Vinten and Meiri, 1990; Bar-tal *et al.*, 1991; Karterji, Van Hoorn, Hamdy and Mastrorilli, 1994; Katerji *et al*., 1996; Abid *et al.,* 2001 and Yazar *et al*., 2003). The fluctuation in osmotic potential adversely affected the physiological availability of water, which is largely a function of the difference between the osmotic potential of the plant root cell and the sum of the osmotic potential of the soil solution (Chabbra, 1996; Munns, 2002a, b). As a result plants are not able to maintain their turgor and thus a reduction in biomass production will occur as a result of the inhibition in photosynthesis. Pasternak, Sagih, Delamach, Keren and Shaffer (1995) and Shani and Dudley (2001) also found that biomass production was significantly affected by saline water when compared to fresh water using different cultivars, which is in agreement with the results found in this study. The severe reduction obtained for leaf area was highly related to the severe reduction of the biomass production. As also found with leaf area, EC_i levels beyond 530 mS m^{-1} lead to a 100% reduction in biomass yield of maize (Figure 4.3).

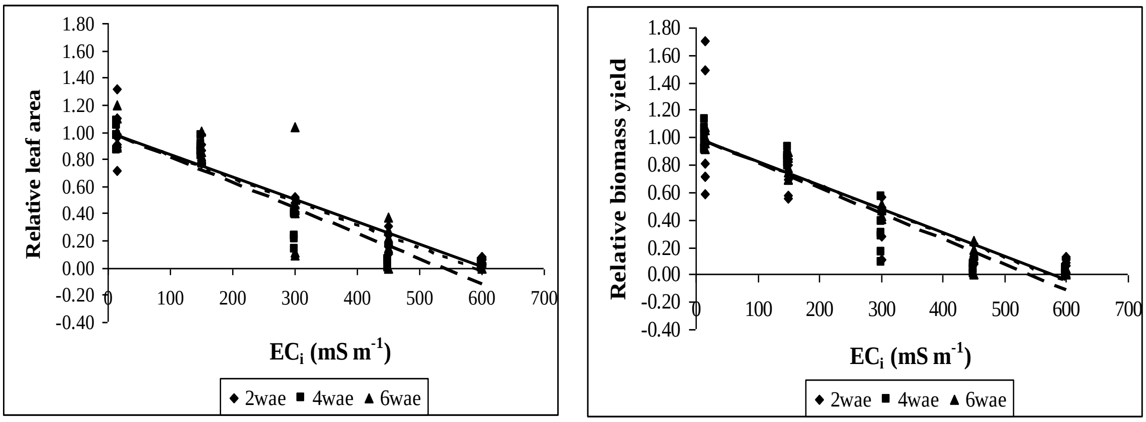


Figure 4.3 The effect of differing EC_i levels (irrigation water salinity) on leaf area and biomass yield at different stages growth (2, 4 and 6 wae are represented by a solid, dashed and dotted line, respectively).

This study found that both leaf area and biomass yield were affected to the same degree and in this case the above ground indicators were seemingly more affected than the below ground indicators.

4.5 CONCLUSIONS

The germination experiment confirmed that maize is regarded as moderately sensitive to saline conditions. Germination percentage was not significantly affected or reduced, however, both coleoptile and root length were significantly affected over the selected EC_i range from 15 to 600 mS m^{-1}. These latter indicators reflect on the quality of the seedling and showed that an inferior quality seedling could be the result of an increase in the salinity of irrigation water.

Interesting findings were obtained with the glasshouse pot experiment with regard to the degree of sensitivity of both below and above ground indicators of maize at different selected intervals (2, 4 and 6 wae). The below ground indicators were affected to the same degree, when compared to above ground indicators (leaf number, leaf area, plant height and stem diameter), especially at 2 and 4 wae. The degree of sensitivity and for that matter reduction increased over time for the below ground parameters as a result of the accumulation of salts in the soil due to continued irrigation in the closed system. With regard to the above ground indicators, both leaf area and biomass were affected to the same degree. Therefore, a reduction in leaf area was proportional to that of biomass yield. It has to be noted that the study was only undertaken for six weeks. Although some plants died as a result of continuous salt accumulation in the soil, it could be concluded that the growth and development of maize plants would be negatively affected at an EC_i of 300 mS m^{-1} and higher under these conditions.

4.6 REFERENCES

ABID, M., QAYYUM, A., DASTI, A.A. & WAJID, R.A., 2001. Effect of salinity and SAR of irrigation water on yield, physiological growth parameters of maize (*Zea Mays* L.) and properties of the soil. *J. of Res. Sci.* (Pakistan) 12, 26-33.

ABROL, I.P., YADAV, J.S. & MASSOUD, F.I., 1988. Salt affected soils and their management. FAO Soils bulletin 39, Rome.

ALDRICH, S.R. & LENG, E.R., 1966. Modern corn production. F & W Printing Corp. Cincinnati.

AYERS, R.S. & WESTCOT, D.W., 1976. Water quality for agriculture. FAO Irrigation and drainage paper 29, Rome.

BACKEBERG, G.R., BEMBRIDGE, T.J., BENNIE, A.T.P., GROENEWALD, J.A., HAMMESS, P.S., PULLEN, R.A. & THOMPSON, H., 1996. Policy proposal for irrigated agriculture in South Africa. Water Research Commission Report KV 96/96, Pretoria.

BAR-TAL, A., FEIGENBAUM, S. & SPARKS, D.L., 1991. Potassium-salinity interactions in irrigated corn. *Irrig. Sci*. 12, 27-35.

BERNSTEIN, L., 1975. Effects of salinity and sodicity on plant growth. *Annu. Rev. Phytopathol.* 13, 295-312.

BENNIE, A.T.P., COETZEE, M.J., VAN ANTWERPEN, R., VAN RENSBURG, L.D. & BURGER, R., 1988. ’n Waterbalansmodel vir besproeiing gebasseer op profiel watervoorsienings-tempo en gewaswaterbehoeftes. Water Research Commission Report no 144/1/88, Pretoria.

BENNIE, A.T.P., VAN RENSBURG, L.D., STRYDOM, M.G. & DU PREEZ, C.C., 1997. Reaksie van gewasse op voorafgeprogrammeerde tekortbesproeiing. Water Research Commission Report no 423/1/97, Pretoria.

CERONIO, G.M., 1997. Invloed van bandgeplaaste stikstof en fosfor op die vroeë groei en ontwikkeling van mielies. M.Sc.Agric. Thesis, University of the Free State, Bloemfontein.

CHABBRA, R., 1996. Soil salinity and water quality. Balkema Publishers. Brookfield, Missouri.

CORDOVILLA, M.D.P., LIGERO, F. & LLUCH, C., 1999. Effect of salinity on growth, nodulation and N assimilation in nodules of faba bean (*Vicia faba* L.). *Appl. Soil Eco*. 11, 1-7.

CUARTERO, J. & MUNOZ, R.F., 1999. Tomato and salinity. *Sci. Hort.* 78, 83-125.

DU PREEZ, C.C., STRYDOM, M.G., LE ROUX, P.A.L., PRETORIOUS, J.P., VAN RENSBURG, L.D. & BENNIE, A.T.P., 2000. Effect of water quality on irrigation farming along the lower Vaal River: The influence on soils and crops. Water Research Commission Report No: 740/1/00, Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY., 1996. South African water quality guidelines, 2nd edition. Volume 4. Agricultural use: Irrigation. Government Printer, Pretoria.

FRENKEL, H., MANTELL, A., VINTEN, A. & MEIRI, A., 1990. Double line-source sprinkler system for determining the separate and interactive effects of water and salinity on forage corn. *Irrig. Sci*. 11, 227-231.

GHASSEMI, F., JAKEMAN, A.J. & NIX, H.A., 1995. Salinisation of land and water resources: Human causes, extent, management & case studies. University of South Wales Press, Australia.

GOMEZ, K.A. & GOMEZ, A.A., 1984. Statistical procedures for agricultural research, 2nd edition. John Wiley & Sons Inc, New York.

HINTZE, J.L., 1998. Number cruncher statistical systems (NCSS 2000). Kaysville, Utah.

HU, Y., CAMP, K.H. & SCHIMDHALTER, U., 2000. Kinetics and spatial distribution of leaf elongation of wheat (*Triticum aestivum* L.) under saline conditions. *Int. J. Plant Sci.* 161, 575-582.

KATERJI, N., VAN HOON, J.W., HAMDY, A., KARAM, F. & MASTRORILLI, M., 1996. Effect of salinity on water stress, growth, and yield of maize and sunflower. *Agric. Water Manage*. 30, 237-249.

KATERJI, N., VAN HOON, J.W., HAMDY, A. & MASTRORILLI, M., 1994. Effect of salinity on emergence and on water stress and early seedling growth of sunflower and maize. *Agric. Water Manage.* 26, 81-91.

KATERJI, N., VAN HOON, J.W., HAMDY, A. & MASTRORILLI, M., 2004. Comparison of corn yield response to plant water stress caused by salinity and drought. *Agric. Water Manage.* 65, 95-101.

LYNCH, J., CRAMER, G.R. & LÄUCHLI, A., 1987. Salinity reduces membrane associated-associated calcium in corn root protoplast. *Plant Physiol.* 83, 390-394.

LYNCH, J., POLITO, V.S. & LÄUCHLI, A., 1989. Salinity stress increases cytoplasmic Ca in maize root protoplasts. *Plant Physiol.* 90, 1271-1274.

MAAS, E.V., 1990. Crop salt tolerance. In K.K. Tanji (ed). Agricultural salinity assessment and management. Am. Soc. Civ. Eng., New York**.**

MAAS, E.V. & HOFFMAN, G.J., 1977. Crop Salt Tolerance: Evaluation of existing data. In E. H. Dregne (ed). Managing saline water for irrigation. Proceedings of the International Salinity Conference, Texas.

MAAS, E.V., HOFFMAN, G.J., CHABA, G.D., POSS, J.A. & SHANNON, M.C., 1983. Salt sensitivity of corn at various growth stages. *Irrig. Sci*. 4, 45-57.

MAAS, E.V. & POSS, J.A., 1989. Salt sensitivity of wheat at various growth stages. *Irrig. Sci*. 10, 29-40.

MUNNS, R., 2002a. Comparative physiology of salt and water stress. *Plant, Cell Environ.* 25, 239-250.

MUNNS, R., 2002b. The impact of Salinity stress. CSIRO division of plant industry. Australia. http://www.plantstress.com/Aricles/index.asp

NATIONAL DEPARTMENT OF AGRICULTURE, 2003. Maize production. Directorate of agricultural information, Pretoria.

PASTERNAK, D., SAGIH, M., DeLAMACH, Y., KEREN, Y. & SHAFFER, A., 1995. Irrigation with brackish water under dessert conditions XI. Salt tolerance in sweet-corn cultivars. *Agric. Water Manage.* 28, 325-334.

RICHARDS, L.A., 1954. Diagnosis and improvement of saline and alkali soils. Government Printing Office, Washington.

RHOADES, J.D. & LOVEDAY, J., 1990. Salinity in irrigated agriculture. In A.B. Steward & D.R. Nielsen (eds). Irrigation of agricultural crops. Agron. Soc Am., Madison, Wiscon.

ROWSE, H.R. & PHILLIPS, D.A., 1974. An instrument for estimating the total length of root in a sample. *J. Appl. Ecol.* 11, 309-314.

SAQIB, M., AKHTAR, J. & QURESHI, R.H., 2004. Pot study on wheat growth in saline and waterlogged compacted soil II. Root growth and leaf ionic relations. *Soil Tillage Res*. 77, 179-187.

SHAINBERG, I. & OSTER, D., 1978. Quality of irrigation water. International irrigation information centre: Publication no: 2, Israel.

SHANI, U. & DUDLEY, I., 2001. Field studies of crop response to water and salt stress. *Soil Sci. Soc. Am. J.* 65, 1522-1528.

SHIRAZI, M.U., ASIF, S.M., KHANZADA, B., KHAN, M.A., ALI, M., MUNTAZ, S., YOSUFZAI, M.N. & SAIF, M., 2001. Growth and ion accumulation in some wheat genotypes under NaCl stress. *Pak. J. of Biol. Sci.* 4, 388-391.

VAN ANTWERPEN, R., 1988. Evaluasie van verskillende empirise modelle vir die voorspelling van wortel groei. M.Sc.Agric. Thesis, University of the Free State, Bloemfontein.

YAZAR, A., GENCEL, B. & SEZEN, M.S., 2003. Corn yield response to saline irrigation water applied with a trickle system. *Food Agric. Environ*. 1, 198-202.

CHAPTER 5

PEAS (*Pisum sativum* L.) AND BEANS (*Phaseolus vulgaris* L.) GROWTH AND YIELD RESPONSE TO SALINE IRRIGATION WATER UNDER CONTROLLED CONDITIONS

5.1 ABSTRACT

Soil salinity is a major limitation to legume production in many areas of the world, especially in irrigated areas. The effect of irrigation water salinity on peas and beans were investigated, where electrical conductivity (EC, mS m^{-1}) was used as a salinity indicator. A pot experiment was conducted, at the University of Free State during 2004 and 2005 for peas (cv. Solara) and beans (cv. Teebus), respectively, to determine the effect of different EC_i levels on germination, growth and yield of these crops. Both crops were subjected to five EC_i levels (15-control, 75, 150, 225, 300 mS m^{-1}) and three growth stages (five weeks after emergence-5 wae, flowering and maturity), which were replicated three times and laid out in a complete randomised design with a factorial combination. A laboratory experiment was also conducted and this study showed that the germination percentage of peas and both the hypocotile and root length of beans were significantly reduced at EC_i levels of 300 and 150 mS m^{-1} respectively. Various morphological indicators were used to quantify the impact of EC_i on the below ground growth of these peas and beans, *viz*. root mass and root length. For above ground growth, mainly leaf area, biomass and one yield component (pod number) were used. Plant indicators were sampled at 5 wae, flowering and maturity. All indicators expressed on a relative basis showed a reduction in growth in relation to an increase in the EC_i levels. The analysis indicated that the below ground and above ground growth were affected to the same degree for peas. However, beans showed with the exception of 5 wae, that the below ground growth was more sensitive to salinity than the above ground growth. The results of the study suggest that peas are relatively more sensitive than beans. However, the final analysis on the yield confirmed the concerns of farmers who experienced yield losses due to salinity. It was proved that peas was more sensitive to salinity than beans, with yield losses of more than double that of beans at the respective EC_i levels.

5.2 INTRODUCTION

Irrigation water salinity as a cause of yield reduction has been the subject of many investigations and this is generally not combined with studies on crop physiology. Soil and water salinity is a major limitation to legume production in many areas of the world due to its sensitivity to salinity (Ayers and Westcot, 1976; Maas and Hoffman, 1977; Maas, 1990). Legumes are considered a relatively salt sensitive family within which limited variability for salinity tolerance has been detected (Maas and Hoffman, 1977; Maas, 1990). Legumes have been suggested as appropriate crops for enhancement of bioproductivity and reclamation of marginal lands, because these plants do not only yield nutritious fodder and protein rich seeds, but they also enrich soil nitrogen. The production of irrigated peas and beans cannot be overlooked as these crops form an integral part of a sustainable crop rotation system. Therefore, the sustainability of irrigation schemes has to be ensured with regard to the quality of irrigation water used.

The unreliability and variability of rainfall in the arid and semi-arid regions makes irrigation a vital component of the agricultural industry in South Africa (Backeberg, Bembridge, Bennie, Groenewald, Hammes, Pullen and Thompson 1996) and this will require not only the availability of water, but also its suitability be considered. Agriculture, especially irrigation farming, is the largest consumer of available water in South Africa (Department of Water Affairs and Forestry - DWAF, 1996). The world population continues to increase and the amount of the arable land decreases. This exerts pressure on the remaining natural resources and necessitates our attention (Fireman and Kraus, 1965; Szabolcs, 1989, Ghassemi Jakeman and Nix, 1995).

Greater emphasis must therefore be placed on bringing marginally productive and presently non-arable land under production (Richards, 1954; Chabbra, 1996). Unfortunately large areas of formerly arable land are being removed from crop production every year due to increasing salinity (Rhoades and Loveday, 1990). The use of marginal quality waters and soils is increasing and this subjects crop plants to increased salinity (Ghassemi *et al.,* 1995). Irrigation water is used to supply water requirements of a wide variety of crops under widely varying degrees of intensification, using a range of different distribution and irrigation systems. Beans and peas are important crops in South Africa and are grown for a variety of purposes but they are sensitive to saline irrigation water. Ayers and Westcot, (1976) reported a 25% yield reduction at an EC_i of 150 mS m^{-1} for beans. Salinity impairs seed germination, reduces nodule formation, retards plant development and reduces crop yields (Bayuelo-Jimenez, Craig and Lynch, 2002a; Bayuelo-Jimenez, Deboouck and Lynch, 2002b). Plant growth, nutrient metabolism, and protein synthesis are all thought to be adversely affected by salt stress conditions (Maas, 1990; Ghassemi *et al*., 1995). Therefore, to establish the suitability of plants for saline agriculture, it is essential to study its response to differing salinity levels (Abid, Qayyum, Dasti and Wajid, 2001).

Many farmers are utilising irrigation water without considering its water quality and its effects, as a result they experience unacceptable yield losses (Du Preez, Strydom, Le Roux, Pretorius, Van Rensburg and Bennie, 2000). Thus, the objective of this study was to quantify the effect of saline irrigation water (EC_i levels) on the germination, growth (at different growth stages) and yield of dry peas (*Pisum sativum* L.) and dry beans (*Phaseolus vulgaris* L.).

5.3 MATERIALS and METHODS

Two experiments were conducted to achieve the objective *viz*. a germination experiment executed in the laboratory and a glasshouse pot experiment for determining the effect of salinity on growth and yield of peas and beans.

5.3.1 Irrigation water solutions

In this experiment five irrigation water quality treatments were also used. The same procedure was used as in section 3.3.1 but the electrical conductivity was lowered. The electrical conductivity (EC) and sodium adsorption ratio (SAR) of irrigation water used is presented in Table 5.1.

Table 5.1 The electrical conductivity (EC_i, mS m^{-1}), sodium adsorption ratio (SAR) and amount of different salts to prepare the required irrigation water quality treatments

	EC_i (mS m^{-1})			
	75	**150**	**225**	**300**
SAR	1.8	3.0	3.0	5.0
TDS (mg ℓ^{-1})	494	988	1229	2003
NaCl (mg ℓ^{-1})	120	360	400	790
$CaCl_2$ (mg ℓ^{-1})	0	100	153	235
$MgSO_4$ (mg ℓ^{-1})	108	297	375	620
Na_2SO_4 (mg ℓ^{-1})	0	20	50	50
KCl (mg ℓ^{-1})	105	120	187	187
$MgCl_2$ (mg ℓ^{-1})	45	80	40	40
Ca: Mg	1:1.32	1:1.31	1:1.31	1:1.31
SO_4: Cl	1:1.33	1:1.33	1:1.31	1:1.32

5.3.2 Germination experiment

The laboratory germination experiment used is described in detail in Section 3.3.2. With reference to section 3.3.2, the only difference was a change in EC levels of the irrigation water as shown in Table 5.1.

5.3.3 Glasshouse pot experiment

This study was conducted in the same asbestos pots described earlier and details can be found in Section 3.3.3. The EC_i levels were lowered as shown in Table 5.1. However, the level of fertiliser application was adapted to the equivalent of 27 kg N, 40 kg P, and 53 kg K ha^{-1} for peas and 15 kg N, 22.5 kg P, and 30 kg K ha^{-1} for beans to a depth of 100 mm. Peas also received a topdressing of 20kg N and beans 69 kg N ha^{-1} at four weeks after emergence for both crops The pots were watered by hand using the same volume of water per event. At the end of each experiment, peas received 97 ℓ of water, while the beans 106 ℓ of water. The applied volume of water was the same for the respective growing seasons that continued until maturity. Peas (cv. Solara) and beans (cv. Teebus) were planted during July 2004 and February 2005 and thinned to three plants per pot and grown in the glasshouse at day/night temperatures of $20/10^0$C and $22/15^0$C for peas and beans, respectively. The experiment was laid out in a complete randomised design with a factorial combination consisting of two main factors, *viz*. five EC_i levels as described and three growth stages [5 wae - five weeks after emergence, flowering (9 wae) and maturity (15 wae)] replicated thrice. Both these experiments were conducted over two seasons but unfortunately the data for both crops were available for only one season each as a result of a *Sclerotinia sclerotium* infection on beans and a fungal infection of the pea seed.

The following indicators were used to evaluate the influence of salinity on both pea and bean growth and yield on a relative basis: leaf area (cm^2 $plant^{-1}$), root length (mm roots mm^{-2} of soil surface), root mass (g plant $^{-1}$), total above-ground biomass, referred to as biomass (g $plant^{-1}$), number of pods ($plant^{-1}$) and seed yield (g $plant^{-1}$). Leaf area was measured with the LICOR 3000 leaf area meter. The compound leaves without petioles of peas and beans were sampled. The biomass was obtained through weighing the harvested produce after it had been dried. Number of pods were visually counted. Seed yield was obtained by weighing the harvested seeds. The experimental data were analysed as described in Section 3.3.3.

5.4 RESULTS and DISCUSSION

5.4.1 Germination percentage, hypocotile and root length

Germination percentage only reflects on the quantity aspects and both crops showed a reduction (7% - beans and 8% - peas) at 300 mS m^{-1}, but only peas was significantly reduced (Table 5.2). Steppuhn, Volkmar and Miller (2001) also reported the emergence of both peas and beans were reduced with an increase in salinity. Failure during this stage will be reflected in the potential and actual yield and therefore the evaluation of both the quantitative and qualitative indicators of the seedlings are inevitable.

Qualitatively only beans proved to be significantly affected. However, both crops showed the same tendency as both coleoptile and root length was reduced with an increase in EC over the EC_i range. Thus the emergence patterns and early survival among these crops within each salinity level were similar at low salinity levels, but at higher levels these crops reacted differently, with beans being more sensitive. Interesting results were obtained with beans as both hypocotile and root length were significantly reduced by 13 and 15% at an EC_i level 150 mS m^{-1}, respectively (Table 5.2). However not significantly affected, peas showed a continuous decrease in hypocotile and root length with increasing EC_i range, which is in agreement with the findings of Shirazi, Asif, Khahzada, Khan, Ali, Muntaz, Yosufzai and

Saif (2001). Therefore, it seems at this stage that beans were more sensitive to saline conditions than peas. The rate of the expansion of these indicators was greatly inhibited by increasing EC_i, which could affect the establishment of the plants. Furthermore, saline solutions delayed germination and emergence and also reduced the root length of the germinating seeds. Therefore, salinity tolerance at germination is important for the crop establishment (Bayuelo-Jimenez *et al*., 2002a).

Table 5.2 Germination percentage, hypocotile and root length affected by different EC_i levels for peas and beans

Plant indicators	**Treatments (mS m^{-1})**					
	15*	75	150	225	300	LSD $_{(0.05)}$
Peas						
Germination (%)	100a	100a	100a	100a	92b	4.18
Hypocotile length (mm)	130a	126a	121a	112a	109a	ns
Root length (mm)	158a	158a	155a	138a	125a	ns
Beans						
Germination (%)	100a	100a	100a	100a	93a	ns
Hypocotile length (mm)	139a	127a	121b	110b	104bc	16.85
Root length (mm)	177a	157a	150b	127b	126b	26.19

* = Control.

ns = not significant.

5.4.2 Response of beans and peas at early vegetative, flowering and maturity stages

The statistical results and regression analysis of all the above ground and below ground plant indicators are presented in Table 5.3 for peas and Table 5.4 for beans. Plant response was expressed on a relative basis for both crops at the early vegetative (5 wae), flowering (9 wae) and maturity (15 wae) stages.

5.4.2.1 Below ground plant response

For discussion of below ground plant response, root mass and root length indicators were used. Irrigation with saline water directly affected both below ground indicators as can be seen from the regression line depicted on a relative scale for various growth stages (Figure 5.1, peas and 5.2, beans). Comparing the effects of salinity at the different growth stages of peas (Figure 5.1), it is obvious that the roots became more sensitive over time. This was confirmed by the statistical results reported in Table 5.3 where the root mass and length of the maturity growth stage was statistically reduced at 150 mS m^{-1} compared to 150 225 mS

m^{-1} for the flowering stage and 300 mS m^{-1} for the early vegetative growth stage. According to Figure 5.2 beans were not that sensitive as peas with regard to salinity on the sequence of growth stages. Rhoades and Loveday (1990) also reported that excess salinity in the root zone adversely affected the growth of established plants by a general reduction in growth rate. Adverse effects of salinity on root growth and concomitant poor plant growth has also been recognised by other researchers (Bayuelo-Jimenez *et al*., 2002a; Bayuelo-Jimenez, Deboouck and Lynch, 2002b; Saqib, Akhtar and Qureshi, 2004).

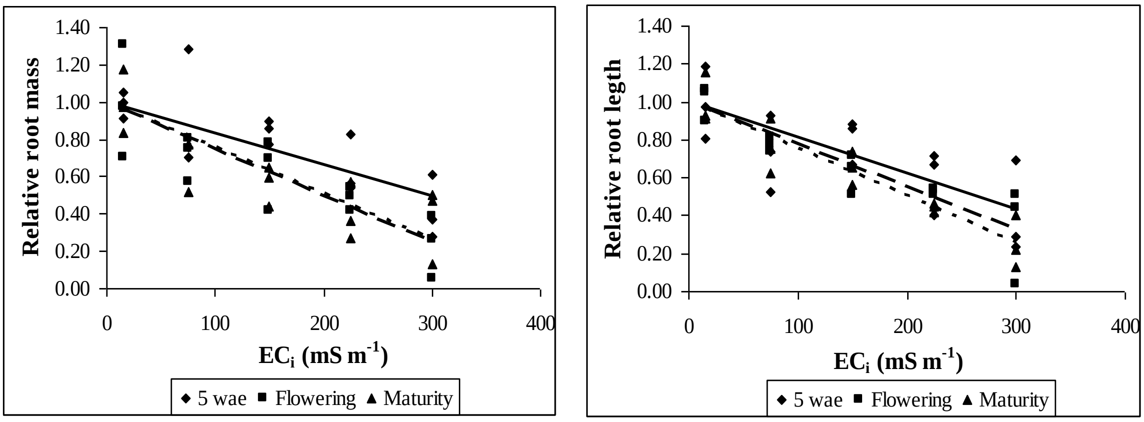


Figure 5.1 The effect of differing EC_i levels (irrigation water salinity) on root length and root mass at different stages of growth on peas (5 wae, flowering and maturity are represented by a solid, dashed and dotted line, respectively).

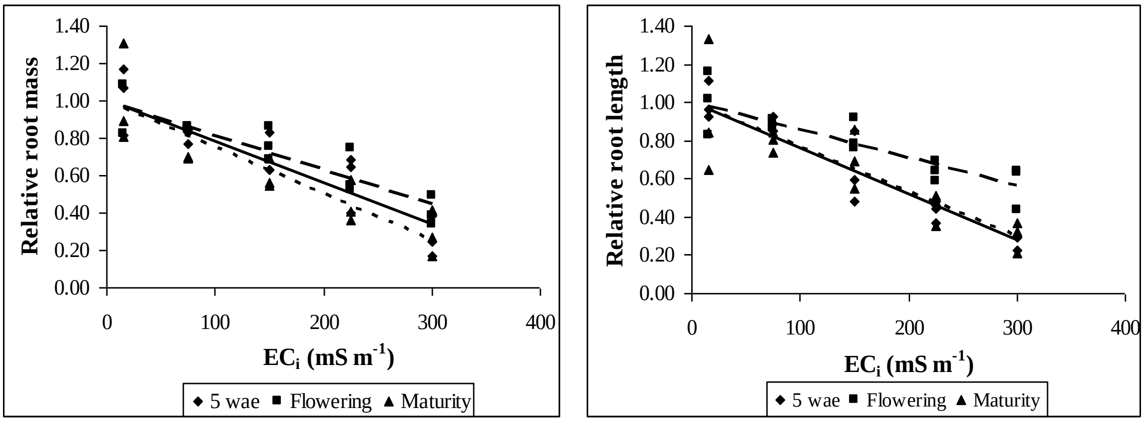


Figure 5.2 The effect of differing EC_i levels (irrigation water salinity) on root length and root mass at different stages of growth on beans (5 wae, flowering and maturity are represented by a solid, dashed and dotted line, respectively).

Table 5.3 Statistical results of the response of peas at early vegetative stage, flowering and maturity to saline irrigation water as indicated by various plant indicators on a relative scale

Plant indicators	Maximum response		Regression coefficients			PR (%)		PSD	
	Unit	Y1	intercept	slope	r^2	150	300	(mS m^{-1})	LSD $_{(0.05)}$
Peas, early vegetative									
Below ground									
Root mass	(g $plant^{-1}$)	0.19	1	-0.0017	0.60	26	51	300	0.50
Root length index	(mm mm^{-2})	0.42	1	-0.0019	0.54	29	57	300	0.51
Above ground									
Leaf area	(cm^2 $plant^{-1}$)	170	1	-0.0025	0.78	38	75	225	0.44
Biomass	(g $plant^{-1}$)	1.54	1	-0.0023	0.70	35	69	225	0.45
Peas, Flowering									
Below ground									
Root mass	(g $plant^{-1}$)	0.92	1	-0.0025	0.70	38	75	225	0.49
Root length index	(mm mm^{-2})	1.04	1	-0.0023	0.80	35	69	150	0.35
Above ground									
Leaf area	(cm^2 $plant^{-1}$)	396	1	-0.0022	0.75	33	66	225	0.44
Biomass	(g $plant^{-1}$)	4.44	1	-0.002	0.51	30	60	ns	ns
Peas, Maturity									
Below ground									
Root mass	(g $plant^{-1}$)	0.47	1	-0.0024	0.64	36	72	150	0.43
Root length	(mm mm^{-2})	0.69	1	-0.0025	0.87	38	75	150	0.31
Above ground									
Biomass	(g $plant^{-1}$)	13.5	1	-0.0021	0.68	32	63	225	0.38
Pod number	($plant^{-1}$)	11	1	-0.0019	0.68	29	57	225	0.40
Seed yield	(g $plant^{-1}$)	7.6	1	-0.0026	0.65	39	78	75	0.34

PR = Percentage reduction observed over the EC_i range estimated with the linear regression equation at 300 and 600 mS m^{-1} and subtracted from the control.

PSD = Point of statistical difference in relation to the control.

* = not significant.

Maximum response = Response obtained by the control plants.

Table 5.4 Statistical results of the response of beans at early vegetative stage, flowering and maturity to saline irrigation water as indicated by various plant indicators on a relative scale

Plant indicators	Maximum response		Regression coefficients			PR (%)		PSD	
	Unit	Y1	intercept	slope	r^2	150	300	(mS m^{-1})	LSD $_{(0.05)}$
Beans, early vegetative									
Below ground									
Root mass	(g $plant^{-1}$)	0.20	1	-0.0022	0.81	33	66	225	0.35
Root length index	(mm mm^{-2})	0.27	1	-0.0024	0.90	36	72	150	0.27
Above ground									
Leaf area	(cm^2 $plant^{-1}$)	495	1	-0.0027	0.82	41	81	150	0.39
Biomass	(g $plant^{-1}$)	2.6	1	-0.002	0.73	30	60	300	0.41
Beans, Flowering									
Below ground									
Root mass	(g $plant^{-1}$)	1.22	1	-0.0019	0.84	29	57	225	0.27
Root length index	(mm mm^{-2})	2.1	1	-0.0015	0.77	23	45	150	0.28
Above ground									
Leaf area	(cm^2 $plant^{-1}$)	1500	1	-0.0009	0.73	14	27	225	0.19
Biomass	(g $plant^{-1}$)	11.17	1	-0.0014	0.81	21	41	150	0.18
Beans, Maturity									
Below ground									
Root mass	(g $plant^{-1}$)	3.07	1	-0.0025	0.76	38	75	150	0.39
Root length	(mm mm^{-2})	3.76	1	-0.0023	0.64	35	69	300	0.60
Above ground									
Biomass	(g $plant^{-1}$)	44.8	1	-0.001	0.68	15	30	300	0.20
Pod number	($plant^{-1}$)	26	1	-0.001	0.62	15	30	300	0.15
Seed yield	(g $plant^{-1}$)	25.3	1	-0.001	0.61	15	30	300	0.22

PR = Percentage reduction observed over the EC_i range estimated with the linear regression equation at 300 and 600 mS m^{-1} and subtracted from the control.

PSD = Point of statistical difference in relation to the control.

Maximum response = Response obtained by the control plants.

5.4.2.2 Above ground plant response

Leaf area and biomass were selected to represent the above ground plant response indicators. According to these indicators as depicted in Figures 5.3 for peas and 5.4 for beans, irrigation with saline water directly reduced the growth of both crops. Hernandez, Olmos, Corpas, Sevilla and Del Rio (1995) also reported a reduction in the leaf area of peas as a result of increased salinity and the premature senescence of leaves (Munns, 2002a, b). According to Steppuhn *et al*. (2001) and Wang, Shannon and Grieve (2001) salinity reduced the photosynthate partitioning to the actively expanding parts of the leaves, thereby affecting the leaf area of the plant. This could be attributed to a significant reduction in cumulative absorption of photosynthetically active radiation (ΣAPAR) and radiation use efficiency

(RUE) (Wang *et al.,* 2001). According to Wang *et al*. (2001) salinity reduced soybean cell expansion and cell wall synthesis and increased stomatal resistance, which ultimately reduced canopy development. Wang *et al.* (2001) also found that salinity affected soybean plants in having smaller and darker green leaves than that of the control, which is in agreement with what was observed for beans in this study. It also has to be noted that the rate at which new leaves are produced depends largely on the water potential of the soil solution (Munns, 2002 a, b). Therefore, an increase in salinity would decrease the soil water potential that will eventually reduce leaf initiation and growth. This reaction is similar to that of drought stressed plants (Chabbra, 1996). Salinity under both moderate and severe conditions progressively decreased the height of peas, beans and other crops (Pessarakli, 1991; Stepphun *et al.,* 2001). Furthermore, it significantly reduced plant growth through a reduction in shoot and root development (Wang *et al*., 2001). The dry weight of cowpeas and other crops also proved to be severely reduced by increased saline conditions, which could be attributed to the physiological and biochemical disorders that lead to the reduced growth rate (West and Francios, 1982; Stepphun *et al.*, 2001; Munns, 2002a, b).

Comparing above ground indicators at different growth stages of peas, as affected by EC_i, showed similar responses. Hence, it seems that the early vegetative growth stage was not more or less sensitive than the reproductive flowering stage. On the other hand, relative leaf area of beans was heavily affected in the early vegetative growth stage but seemed to recover at flowering. Relative biomass response of beans (Figure 5.4) illustrates this recovery process.

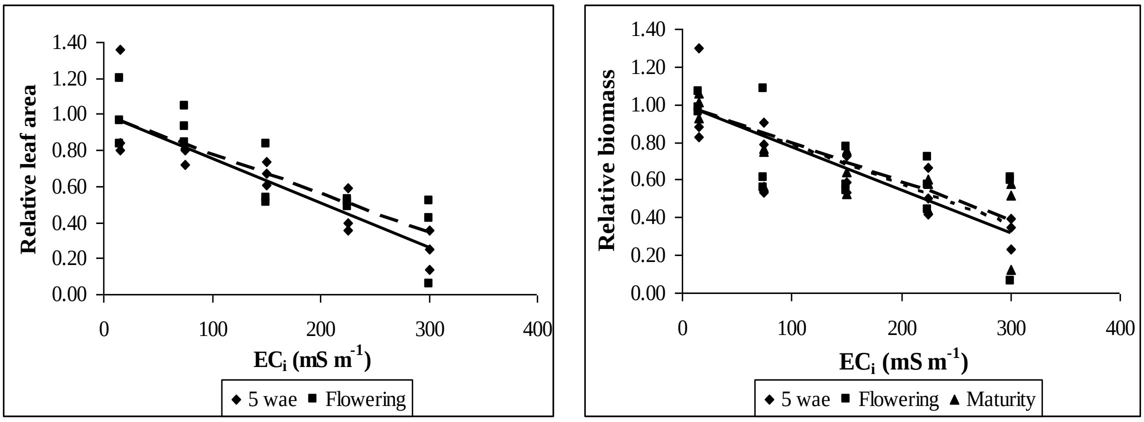


Figure 5.3 The effect of differing EC_i levels (irrigation water salinity) on leaf area and biomass at different stages of growth on peas (5 wae, flowering and maturity are represented by a solid, dashed and dotted line, respectively).

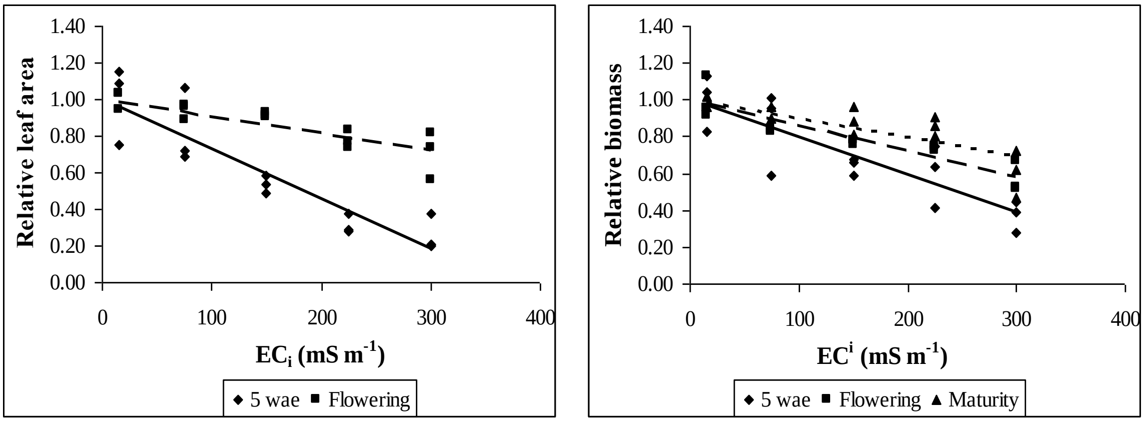


Figure 5.4 The effect of differing EC_i levels (irrigation water salinity) on leaf area and biomass at different stages of growth on beans (5 wae, flowering and maturity are represented by a solid, dashed and dotted line, respectively).

5.4.2.3 Yield and number of pods per plant

The ultimate yield is normally directly proportional to the stress imposed on the plants, in this case salinity. The number of pods was significantly reduced at 225 and 300 mS m^{-1} for peas and beans respectively. Comparing the number of pods per plant at 300 mS m^{-1} for peas and beans, it was evident that peas was more sensitive than beans, with a reduction of 57% compared to 30% of beans. Steppuhn *et al*. (2001) also found that the number of pods of both field pea and dry bean were reduced, and contributed this to the effect of salinity on flowering and ultimately pod formation. Similar results were obtained for cowpeas (West and

Francois, 1982). As expected the regression lines suggested that this particular yield component was more affected in peas than in beans as a result of increasing EC_i level of the irrigation water (Figure 5.5). Cerda, Caro and Fernandez (1982), West and Francois, 1982 and Hafeez, Aslam and Malik (1988) reported that pod density (pods m^{-2}) of cowpeas, pod number and fresh weight of peas and mung beans were significantly reduced following a gradual increase in soil salinity. A disturbance in metabolic activities will impair plant growth and yield, especially during the reproductive stage. According to West and Francois (1982) reduced dry weight could be attributed to higher concentrations of toxic elements, such as sodium and chloride.

A direct relationship exists between pod number $plant^{-1}$ and the seed yield plant. A reduction in this yield component would significantly reflect on the ultimate seed yield, as shown in Figure 5.5. Seed yield of peas was significantly reduced at an EC_i level of 75 mS m^{-1} compared to 300 mS m^{-1} for beans. Salinity impairs germination, reduces nodule formation, retards plant development and as a result the crop yields is reduced (Cerda *et al.,* 1982; Hafeez *et al.,* 1988; Maas, 1990, Steppuhn *et al*., 2001) and unfortunately crop yields are usually markedly reduced before visual symptoms of salinity damage becomes apparent.

Seed yield of peas was more affected than the pod number, but in case of beans both seed yield and pod number was affected in the same way. Salinity affects the formation and the viability of reproductive organs in plants and this is a result of a growth depression that could result from a water deficit, ion imbalance and ion toxicity and as a result seed yield is significantly reduced in high substrate salinity conditions (West and Francois, 1982; Kurban, Saneoka, Nehira, Adilla, Premachandra and Fujita**,** 1999; Steppuhn *et al*., 2001). Generally, yield and in particular the pod yield component (pods $plant^{-1}$) revealed that peas were more sensitive than beans (Figure 5.5).

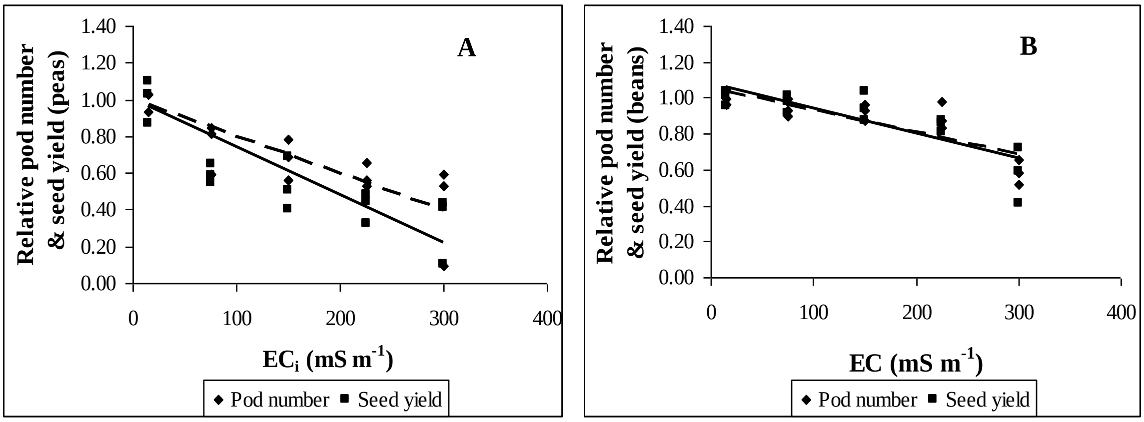


Figure 5.5 The effect of differing ECi levels (irrigation water salinity) on pod number and seed yield for peas (A) and beans (B) (seed yield and pod number are represented by a solid and dashed line, respectively).

5.5 CONCLUSIONS

The effect of selected range of saline irrigation water was evident on all the measured indicators for both peas and beans. Interesting results on the germination experiment confirmed that beans and peas are sensitive to salinity. Both the quantitative and qualitative indicators, though not always significant, showed a reduction with an increase over the EC_i range. At this stage it seemed that beans was more sensitive than peas with regard to the quantitative germination indicators at an EC_i of 150 mS m^{-1} and higher.

Salinity as a form of soil and water stress generally has a detrimental effect on plant growth, and crops such as peas and beans are known for their sensitivity. Interesting results were obtained with the glasshouse pot experiment to the sensitivity of the below and above ground growth of peas and beans to ECi (15 to 300 mS m-1) at 5 wae, flowering and maturity growth stages. The degree of reduction of the below ground indicators of peas remained constant but that of beans increased with increasing EC_i levels over time. The above ground indicators showed that peas was most sensitive to salinity at maturity compared to beans. This was also supported by the results obtained by the yield component of peas that was reduced by more than double that of beans. The reduction in yield was almost 2.5 times more for peas (39%) than beans (15%) at 150 mS m^{-1}. Therefore, it could also be concluded that peas were more sensitive to the range of irrigation water salinity levels than beans.

5.6 REFERENCES

ABID, M., QAYYUM, A., DASTI, A.A. & WAJID, R.A., 2001. Effect of salinity and SAR of irrigation water on yield, physiological growth parameters of maize (*Zea Mays* L.) and properties of the soil. *J. of Res. Sci* (Pakistan) 12, 26-33.

AYERS, R.S. & WESTCOT, D.W., 1976. Water quality for agriculture. FAO Irrigation and drainage paper 29, Rome.

BACKEBERG, G.R., BEMBRIDGE, T.J., BENNIE, A.T.P., GROENEWALD, J.A., HAMMESS, P.S., PULLEN, R.A. & THOMPSON, H., 1996. Policy proposal for irrigated agriculture in South Africa. Water Research Commission Report KV 96/96, Pretoria.

BAYUELO-JIMENEZ, J., CRAIG, R. & LYNCH, J., 2002a. Salinity tolerance of *Phaseolus* species during germination and early seedling growth. *Crop Sci*. 42, 1584-1594.

BAYUELO-JIMENEZ, J., DEBOOUCK, D.R. & LYNCH, J., 2002b. Salinity tolerance in *Phaseolus* species during early vegetative growth. *Crop Sci*. 42, 2184-2192.

CERDA, A., CARO, M. & FERNANDEZ, F.G., 1982. Salt tolerance of two pea cultivars. *Agron. J.* 74, 796-798.

CHABBRA, R., 1996. Soil salinity and water quality. Balkema Publishers, Brookfield, Missouri.

DU PREEZ, C.C., STRYDOM, M.G., LE ROUX, P.A.L., PRETORIOUS, J.P., VAN RENSBURG, L.D. & BENNIE, A.T.P., 2000. Effect of water quality on irrigation farming along the lower Vaal River: The influence on soils and crops. Water Research Commission Report No: 740/1/00, Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1996. South African water quality guidelines, 2nd edition. Volume 4. Agricultural use. Government Printer, Pretoria.

FIREMAN, M. & KRAUS, M., 1965. Salinity Control in Irrigated Agriculture. Tahal, Israel.

GHASSEMI, F., JAKEMAN, A.J. & NIX, H.A., 1995. Salinisation of land and water resources: Human causes, Extent, Management & Case Studies. University of South Wales Press, Australia.

GOMEZ, K.A. & GOMEZ, A.A., 1984. Statistical procedures for agricultural research. 2nd edition. John Wiley & Sons Inc, New York.

HAFEEZ, F.Y., ASLAM, Z. & MALIK, K.A., 1988. Effect of salinity and incubation on growth, nitrogen fixation and nutrient uptake of *Vigna radiata* (L.) Wilczek. *Plant Soil* 106, 3-8.

HERNANDEZ, J.A., OLMOS, E., CORPAS, F.J., SEVILLA, F. & DEL RIO, L.A., 1995. Salt-induced oxidative stress in chloroplast of pea plants. *Plant Sci.* 105, 151-167.

HINTZE, J.L., 1998. Number cruncher statistical systems (NCSS 2000). Kaysville, Utah.

KURBAN, H., SANEOKA, H., NEHIRA, K., ADILLA, R., PREMACHANDRA, G.S. & FUJITA, K., 1999. Effect of salinity on growth, photosynthesis and mineral composition in leguminous plant *Alhgi pseudoalhagi (Bieb.). Soil Sci. Plant Nutr*. 45, 851-862.

MAAS, E.V., 1990. Crop Salt Tolerance. In K.K Tanji (ed). Agricultural Salinity Assessment and Management. Am. Soc. of Civ. Eng., New York.

MAAS, E.V. & HOFFMAN, G.J., 1977. Crop Salt Tolerance: Evaluation of existing data. In E. H. Dregne (ed). Managing saline water for irrigation. Proceedings of the International Salinity Conference, Texas.

MUNNS, R., 2002a. Comparative physiology of salt and water stress. *Plant, Cell Environ.* 25, 239-250.

MUNNS, R., 2002b. The impact of salinity stress. CSIRO division of plant industry, Australia. http://www.plantstress.com/Aricles/index.asp

PESSARAKLI, M., 1991. Dry matter yield, nitrogen-15 absorption, water uptake by green beans under sodium chloride stress. *Crop Sci.* 31, 1633-1640.

RICHARDS, L., 1954. Diagnosis and improvement of saline and alkali soils. Government Printing Office, Washington.

RHOADES, J.D. & LOVEDAY, J., 1990. Salinity in irrigated agriculture. In A.B. Steward & D.R. Nielsen (eds). Irrigation of agricultural crops. *Agron. Soc. Am.*, Madison, Wiscon.

ROWSE, H.R. & PHILLIPS, D.A., 1974. An instrument for estimating the total length of root in a sample. *J. Appl. Ecol.* 11, 309-314.

SAQIB, M., AKHTAR, J. & QURESHI, R.H., 2004. Pot study on wheat growth in saline and waterlogged compacted soil II. Root growth and leaf ionic relations. *Soil, Tillage Res*. 77, 179-187.

SHIRAZI, M.U., ASIF, S.M., KHANZADA, B., KHAN, M.A., ALI, M., MUNTAZ, S., YOSUFZAI, M.N. & SAIF, M., 2001. Growth and ion accumulation in some wheat genotypes under NaCl stress. *Pak. J. Biol. Sci.* 4, 388-391.

STEPPUHN, H., VOLKMAR, K.V. & MILLER, P.R., 2001. Comparing canola, field pea, dry bean, and durum wheat crops grown in saline media. *Crop Sci.* 41, 1827-1833.

SZABOLCS, I., 1989. Salt-affected soils. CRC Press, Baco Raton, Florida.

WANG, D., SHANNON, M.C. & GRIEVE, C.M., 2001. Salinity reduces radiation absorption and use efficiency in soybean. *Field Crops Res.* 69, 267-277.

WEST, D.W. & FRANCOIS, L.E., 1982. Effect of salinity on germination, growth and yield of cowpea. *Irrig. Sci.* 3, 169-175.

CHAPTER 6

COMPARISON OF CROP RESPONSE TO VARIOUS SALINITY LEVELS

6.1 ABSTRACT

The build up of salts in water can cause a drop in the osmotic potential of the water, but could also cause a build up of potentially toxic ions in the soil. Therefore, the effect of irrigation water salinity was quantified on different crops (wheat-cv. SST 806, maize-c.v PNR 6335, peas-cv. Solara and beans-cv. Teebus) and their responses were compared. This study was conducted at the University of Free State from 2003 until 2005. Germination and glasshouse pot experiments were conducted and the selected crops were subjected to five EC_i levels (15-control, 150, 300, 450, 600 for wheat and maize and also additional 1200 mSm^{-1} for wheat and 15-control, 75, 150, 225, 300 $mS\ m^{-1}$ for peas and beans). The leaf area and root mass results for the second growth stage and the above-ground biomass and seed yield for the third growth stage for beans, peas and wheat are presented. Maize was only grown for six weeks and therefore all indicators used were for the six weeks after emergence stage. Only the selected indicators were used as they are considered to be the primary growth indicators that determine plant performance and eventually seed yield. For the germination laboratory experiment, germination percentage (quantitative) and coleoptile (grasses), hypocotile (legumes) and root length (qualitative) were used. These indicators were negatively affected by increasing EC_i levels at varying degrees, depending on the sensitivity of the crop to salinity. The results of these crops were compared on a relative basis. The EC_e was also measured in order to determine the rate at which the soil was salinising and was found to be 2 to 3 times higher than that of irrigation water (EC_i). The reduction in total biomass was linearly related to the EC_e and based on regression coefficients, an attempt was made to come up with salinity threshold values for selected crops. The variation of the plants' ability to grow under saline conditions was also considered during comparison and the results of this study confirmed the salt tolerance classification with wheat to be moderately tolerant, maize moderately sensitive and beans and peas as sensitive.

6.2 INTRODUCTION

The fitness of water for various uses in the protection of aquatic ecosystems, is described by its physical, chemical and aesthetic properties and is controlled by constituents that are either dissolved or suspended in the water (Department of Water Affairs and Forestry, 1996). The composition of dissolved or suspended constituents determines the quality of irrigation water, and is therefore an important consideration when evaluating the salinity conditions of any irrigated area (Richards, 1954).

According to Russell (1973) the yield of a wide variety of crops is reduced by saline conditions and the tolerance of plant's to overcome this abiotic stress is quantified in terms of survival rate or the plant's growth abilities in these conditions. It must, however, be emphasised that using such crops will have only a temporary beneficial effect, economically, and will not prevent the further degradation of the soil. Salinity is a major limitation to crop production in many areas of the world, including South Africa. Soil water losses through evaporation and transpiration causes a rise in the salt concentration of the soil solution in the root zone of 2 to 5 times higher than that of irrigation water (Shainberg and Oster, 1978; Chabbra, 1996).

The build up of salts in water causes a drop in the osmotic potential of the water, but could also cause a build up of potentially toxic ions (Abrol, Yadav and Massoud, 1988; Läuchli and Epstein, 1990). When growth inhibition or depression is caused by a decrease in the osmotic potential it is termed an osmotic effect, but when caused by specific ions that lead to nutrient imbalances or toxicity it is termed a specific ion effect. Saline conditions could also adversely influence plant growth as a result of the high pH levels, the poor physical condition of the soil and the inhibition of nutrient uptake (FSSA, 2003). The adverse effects of salt-affected soils on plant growth are manifested in the form of decreased germination, a decrease in leaf expansion and ultimately leaf area, stomatal conductance, biomass accumulation and eventually seed yield (Katerji, Van Hoorn, Hamdy, Karam and Mastrorilli, 1996, Abid, Qayyum, Dasti and Wajid, 2001; Cramer, Schmidt and Bidart, 2001; Saqib, Akhtar and Qureshi, 2004a).

Excessive water salinity is a constant threat to the sustainability of irrigated crop production (Ramoliya and Pandey, 2001). Attempts have been made to compare different crops to varying levels of salinity (Mass and Hoffman, 1977; Rhoades and Loveday, 1990; Steppuhn, Volkmar and Miller, 2001). It is imperative to know the salt tolerance of different crops when saline irrigation water is to be used, or where salt build up occurs in soils. Separating salinity stress from other induced stresses is difficult because of increased salts altering the ionic balance in the plant and affecting the water availability to plants.

Plants vary tremendously in their ability to grow under saline conditions. Results from crop salt tolerance tests conducted worldwide between 1950 and 1975 were reviewed by Maas and Hoffman (1977). According to Maas and Hoffman (1977) crops have been grouped into four categories of sensitivity to saline conditions, namely sensitive, moderately sensitive, moderately tolerant and tolerant. Following that, these crops were rated as moderately tolerant (wheat), moderately sensitive (maize) and sensitive (beans and peas). Plant parts are generally not equally affected by salinity and therefore it is important to compare the responses of different crops to increasing salinity levels. The criteria used to establish the threshold of tolerance for the different crops was set at a yield loss of 10%. In this chapter only leaf area, root mass, above ground biomass and seed yield were considered because these are the primary growth indicators that determine the plant performance and eventually the seed yield.

Therefore, the objectives of this chapter were to use germination and glasshouse experiment data to: i) quantify the effect of increasing irrigation water EC_i level on the establishment, growth and yield of crops; ii) compare the response of selected crops to varying EC_i levels; and iii) determine at what level of irrigation water (EC_i) and soil salinity the crops show any inhibition.

6.3 MATERIALS and METHODS

A description of both laboratory and glasshouse experiments for different crops is given in section 3.3 (wheat), 4.3 (maize) and 5.3 (beans and peas). Various plant indicators were measured but only leaf area, root mass, above ground biomass and seed yield were selected and discussed in this chapter.

In addition to the plant indicators soil samples were also taken from the pots after leaching with the irrigation water, thus the beginning of each experiment and in the end after harvesting. The electrical conductivity of the saturated paste was determined and the mean of the two values was expressed as EC_e in mS m^{-1}.

6.4 RESULTS and DISCUSSION

6.4.1 Germination experiments

Quantitative and qualitative plant indicators were used to describe the effect of saline irrigation water on germination, *viz*. germination percentage (quantitative) and coleoptile/hypocotile length and root length (qualitative) as shown in Table 6.1.

Table 6.1 The effect of increasing irrigation water EC levels on the germination percentage, coleoptile or hypocotile length and root length of the selected crops

Plant indicator	**Treatment (EC_i mS m^{-1})**					**LSD (0.05)**
	15*	75	150	225	300	
Beans:						
Germination (%)	100a	100a	100a	100a	93a	ns
Hypocotile length (mm)	139a	127a	121b	110b	104b	16.85
Root length (mm)	177a	157a	150b	127b	126b	26.19
Peas:						
Germination (%)	100a	100a	100a	100a	92b	4.18
Hypocotile length (mm)	130a	126a	121a	112a	109a	ns
Root length (mm)	158a	158a	155a	138a	125a	ns
	15	150	300	450	600	
Maize:						
Germination (%)	98a	98a	97a	97a	97a	ns
Coleoptile length (mm)	149a	135a	131b	117b	110bc	16.80
Root length (mm)	182a	170a	160a	137b	133b	29.69
Wheat:						
Germination (%)	100a	99a	97a	99a	100a	ns
Coleoptile length (mm)	150a	145a	147a	128a	136a	ns
Root length (mm)	112a	109a	108a	103a	98a	ns

* = Control.

ns = not significant.

6.4.1.1 Quantitative growth analysis on germination

Comparing germination percentage of the different crops showed that, with the exception of peas, no significant differences were obtained with the selected range of EC_i levels. At a level of 300 mS m^{-1} the germination percentage of peas was significantly reduced to 92%. No significant reduction in the germination percentage of beans was obtained, although the germination percentage was reduced to 93% at 300 mS m^{-1}. These findings are also supported by that of Steppuhn *et al.* (2001), who found that increased soil salinity reduced the emergence of peas and beans. The germination percentage of maize and wheat proved not to be affected by the increasing salinity levels. It is important to mention that germination percentage is only a quantitative measurement and does not reflect the quality of the germinated seedlings.

6.4.1.2 Qualitative growth analysis on germination

The coleoptile/hypocotile length as well as the root length of the germinating seedlings were measured and evaluated to establish if the quality of the seedlings were markedly affected by the selected EC_i treatment levels. Interesting results were obtained on this aspect, as both coleoptile/hypocotile and root length showed a continuous decrease in length with an increase in the EC_i levels of the wetting solution for all crops (Table 6.1). For example, the germination of beans was apparently not affected by the salinity of the irrigation water, but both the qualitative indicators showed a significant reduction in growth at levels of 150 mS m^{-1} and higher. This is a clear indication that the quality or vigour of the seedlings was reduced by the increase in EC_i levels, producing weaker seedlings. The reduction in hypocotile and root length also corresponds with the findings of Steppuhn *et al*. (2001) and Bayuelo-Jimenez, Craig and Lynch, (2002). The results of peas suggest that the roots (21% reduction in length) are more sensitive to salinity than the hypocotiles (16% reduction in length), though no significant differences were obtained. The quality of maize seedlings on the other hand was slightly less affected by reductions in the coleoptile and root length. The coleoptile length was significantly reduced by 12% at 300 mS m^{-1} and the root length significantly by 25% at 450 mS m^{-1} in comparison to the control. Wheat seedlings showed to be the most tolerant of the crops investigated, as both the quality indicators did not significantly affect germination. According to Maas and Hoffman (1977) and Maas (1990) wheat is classified as moderately tolerant to saline conditions.

Although the germination percentage of beans and maize were not significantly affected, the quality of the seedlings was affected with a reduction in the coleoptile/hypocotile and root lengths. This could lead to poorly established seedlings that may eventually die off as a result of primary stress (salt) or secondary stress (nutrient uptake, water uptake or susceptibility to disease). Germination and seedling emergence are two indispensable parameters for the establishment of crops and are of utmost importance in crops that do not have favourable compensation ability, such as wheat compared to the other selected crops. Therefore, a reduction of 10% in the stand or establishment of seedlings could lead to significant economic losses.

6.4.2 Glasshouse pot experiments

6.4.2.1 Effect of increasing EC_i (salinity) levels on selected plant indicators

The summary of statistical results of all above- and below-ground plant indicators are presented in Table 6.2. Results for beans and peas were obtained during one season of growth, but for maize and wheat the observations were obtained over two seasons. Apparently it seems that conditions were slightly better during the second growing season compared to the first growing season of wheat. This could mainly be ascribed to the fact that the planting date of the second season was one month earlier than for the first season, therefore the second season's growth period was longer. However, when expressing the salinity response of wheat to its maximum response of a particular season, the results showed no significant difference in its response between seasons. Therefore, the data of the two seasons were combined for analysis. The same applied for maize, though no apparent difference was observed for all indicators between the different seasons.

As shown in Figures 6.1 to 6.4 the discussion on the reaction of growth and yield indicators is presented in relative values, which was obtained by dividing the treatment values by the control value. In all four figures the level of first significant difference compared to the control, is indicated by a vertical line. The leaf area and root mass results for the second growth stage and the above-ground biomass and seed yield for the third growth stage for beans, peas and wheat are presented. Maize was only grown for six weeks and therefore all indicators used are for the six weeks after emergence stage.

Table 6.2 Summary of the level from where salinity significantly reduced the different plant indicators of the selected crops

Growth stage	Beans	EC_I level (mS m^{-1})	Peas	EC_i level (mS m^{-1})	Maize	EC_i level (mS m^{-1})	Wheat	EC_i level (mS m^{-1})
1	Leaf area	* ≥ (150)	Leaf area	* ≥ (225)	Leaf count	* ≥ (300)	Plant height	* ≥ (150)
	Root length	* ≥ (150)	Root length	* ≥ (300)	Stem diameter	* ≥ (300)	Leaf area	* ≥ (300)
	Root mass	* ≥ (225)	Root mass	* ≥ (300)	Plant height	* ≥ (300)	Number of tillers	* ≥ (300)
	Biomass	* ≥ (300)	Biomass	* ≥ (225)	Leaf area	* ≥ (300)	Root length	* ≥ (300)
					Root length	* ≥ (300)	Root mass	* ≥ (300)
					Root mass	* ≥ (450)	Biomass	* ≥ (300)
					Biomass	* ≥ (300)		
2	Leaf area	* ≥ (225)	Leaf area	* ≥ (225)	Leaf count	* ≥ (300)	Plant height	* ≥ (150)
	Root length	* ≥ (150)	Root length	* ≥ (150)	Stem diameter	* ≥ (300)	Leaf area	* ≥ (300)
	Root mass	* ≥ (225)	Root mass	* ≥ (225)	Plant height	* ≥ (150)	Number of tillers	* ≥ (300)
	Biomass	* ≥ (150)	Biomass	ns	Leaf area	* ≥ (300)	Root length	* ≥ (300)
					Root length	* ≥ (300)	Root mass	* ≥ (300)
					Root mass	* ≥ (300)	Biomass	* ≥ (300)
					Biomass	* ≥ (150)		
3	Root length	* ≥ (300)	Root length	* ≥ (150)	Leaf count	* ≥ (450)	Plant height	* ≥ (300)
	Root mass	* ≥ (150)	Root mass	* ≥ (150)	Stem diameter	* ≥ (450)	Number of tillers	* ≥ (450)
	Biomass	* ≥ (300)	Biomass	* ≥ (225)	Plant height	* ≥ (300)	Root length	* ≥ (300)
	Pods $plant^{-1}$	* ≥ (300)	Pods $plant^{-1}$	* ≥ (225)	Leaf area	* ≥ (300)	Root mass	* ≥ (150)
	Seed yield	* ≥ (300)	Seed yield	* ≥ (75)	Root length	* ≥ (150)	Biomass	* ≥ (300)
					Root mass	* ≥ (150)	Number of ears	* ≥ (450)
					Biomass	* ≥ (150)	Seed yield	* ≥ (300)
							Seed mass ear^{-1}	* ≥ (600)
							100 seed weight	* ≥ (450)

* = Significant different from the control at P≤ 0.05, ns = not significant.

6.4.2.1.1 Relative leaf area

According to the regression functions fitted to the relative leaf area at the EC_i treatments, the relative leaf area of all crops declined as a result of increasing EC_i (Figure 6.1). The mean maximum were 141 508 cm m^{-2} for wheat and 4 587, 1 501 and 396 cm^2 $plant^{-1}$ for maize, beans and peas, respectively (Table 6.3). Significant reduction in leaf area was obtained from EC_i levels of 225 mS m^{-1} for both beans and peas and of 300 mS m^{-1} for both maize and wheat compared, to the control treatment.

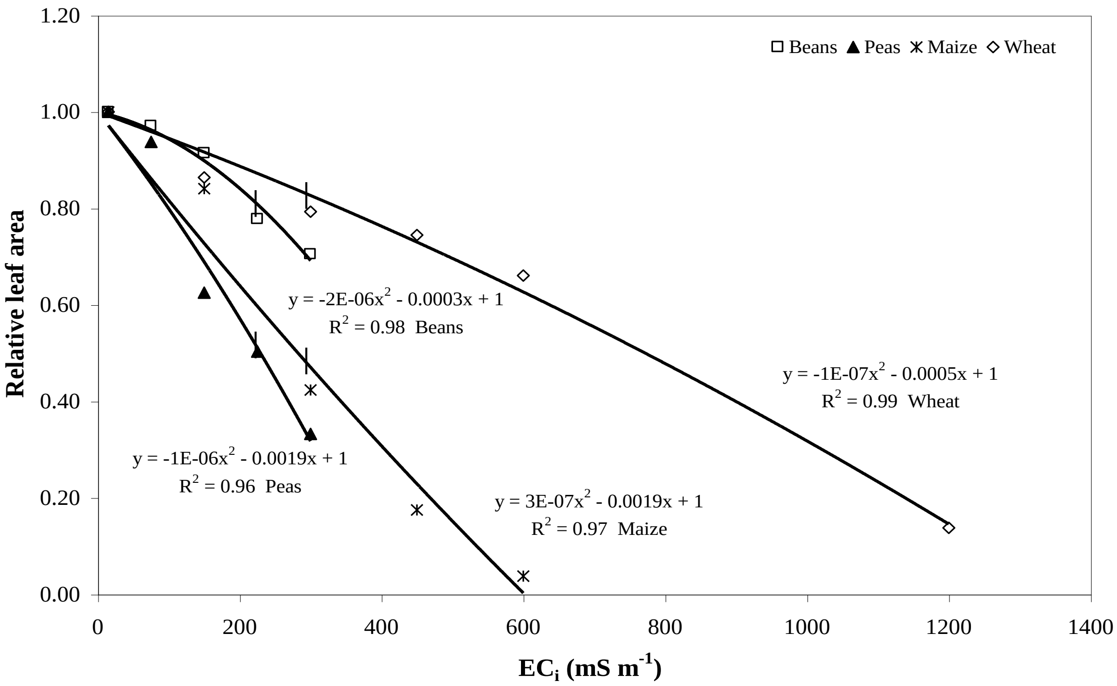


Figure 6.1 Response of relative leaf area of the selected crops to increase in different EC_i levels. The vertical line (I) indicates the onset of the first significant difference ($P \leq 0.05$) compared to the control.

The percentage reduction in leaf area at the different EC_i levels has been summarised in Table 6.3. Comparing the reduction in relative leaf area as a result of increasing salinity demonstrated that peas is the most sensitive crop with regard to relative leaf area followed by maize, beans and wheat. This tendency was valid for all EC_i levels. At 300 mS m^{-1} peas suffered a reduction of 66% compared to reductions of 54, 27 and 16% for maize, beans and wheat respectively. One has to bear in mind that the data collected for maize was not for the full growth cycle, but only for very early vegetative stage of growth and development at 6 weeks. The reason for this is that the pots could only sustain maize growth up to 7 weeks after emergence without having a negative effect on growth as a result of the confined soil volume.

Table 6.3 Relative leaf area reduction (%) of selected crops at different EC_i levels

Crop	**Average* (cm^2 $plant^{-1}$)**	**EC_i level ($mS\ m^{-1}$)**							
		15	**75**	**150**	**225**	**300**	**450**	**600**	**1200**
Wheat	** 141 508	0	4	8	12	16	25	34	74
Maize	4 587	0	14	28	41	54	79	100	-
Beans	1 501	0	3	9	17	27	-	-	-
Peas	396	0	15	31	48	66	-	-	-

* Average maximum leaf area for the control (15 $mS\ m^{-1}$)

** $cm\ m^{-2}$

It is well known that salinity and leaf area are usually inversely related (Maas and Hoffman, 1977) and therefore results obtained for these experiments confirmed this. Declines in leaf area as a result of increasing salinity were also reported by Katerji *et al*. (1996) and Abid *et al*. (2001) on maize; Saqib *et al.* (2004a) on wheat and Steppuhn *et al*. (2001) on canola, field pea, dry bean and durum wheat.

6.4.2.1.2 Relative root mass

Sharp declines in root mass, expressed relative to the control value, with increasing EC_i levels are illustrated in Figure 6.2 for the selected crops. The regression lines in Figure 6.2 represent the relative values for the second growth stage of beans, peas and wheat and those of maize at 6 wae. The real control values used to calculate the relative values were 151.8 g m^{-2} for wheat and 17.5, 1.2 and 0.9 g $plant^{-1}$ for maize, beans and peas, respectively (Table 6.4). Significant differences were obtained for EC_i levels of higher than 225 $mS\ m^{-1}$ for both beans and peas and from 150 $mS\ m^{-1}$ for maize and 300 $mS\ m^{-1}$ for wheat, compared to the control treatment.

The percentage reduction in root mass, compared to the control, at the different EC_i levels have been summarised in Table 6.4. Comparing the reduction in relative root mass indicated that peas is the most sensitive crop with regard to reduction in root mass, followed by maize, beans and wheat. This tendency was valid for all EC_i levels. Root mass of peas was reduced by 73% at 300 $mS\ m^{-1}$, while that of maize, beans and wheat was reduced by 57, 55 and 40%

respectively. The results of these experiments support the findings of Cordovilla, Ligero and Lluch (1999), who also reported a reduction in root dry weight as a result of salinity.

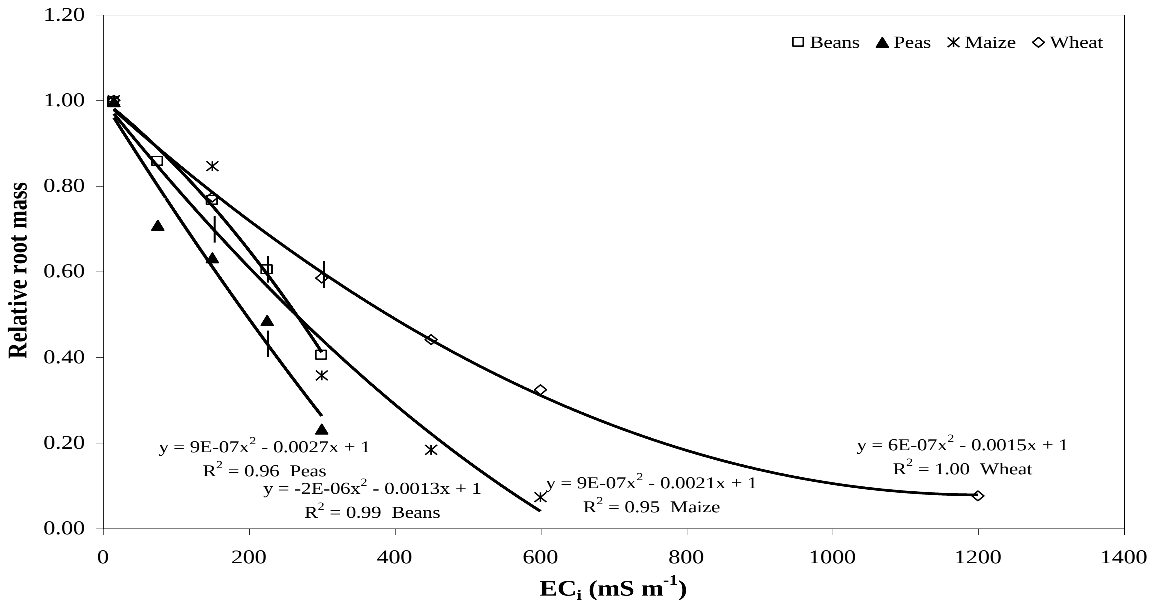


Figure 6.2 Response of relative root mass of the selected crops to increase in different EC_i levels. The vertical line (I) indicates the onset of the first significant difference ($P \leq 0.05$) compared to the control.

Table 6.4 Relative root mass reduction (%) of selected crops at different EC_i levels

Crop	Average* (g plant $^{-1}$)	EC_i level (mS m^{-1})							
		15	75	150	225	300	450	600	1200
Wheat	** 151.8	0	11	21	31	40	55	68	94
Maize	17.5	0	15	29	43	55	76	94	-
Beans	1.2	0	11	24	39	57	-	-	-
Peas	0.9	0	20	38	56	73	-	-	-

* Average maximum root mass measured in the control (15 mS m^{-1})

** g m^{-2}

Munns and Rawson (1999) and Saqib *et al.* (2004b) also found a reduction in root mass with increasing salinity at different growth stages. Excess salinity in the root zone also adversely affects already established plants through a reduction in root growth (Rhoades and Loveday, 1990). Accordingly, salt stress conditions may induce morphological and structural changes in roots that could lead to a reduction in the rate of root elongation. Saline conditions can promote desiccation of root cells, where the roots die from their tips backwards, which is escalated in dryer parts of the root medium (Rhoades and Loveday, 1990; Saqib**,** Akhtar and Qureshi *et al*., 2004b).

6.4.2.1.3 Relative biomass

A decline in the relative biomass of all crops was observed as a result of irrigation water salinity (Figure 6.3). The relative biomass values in Figure 6.3 were calculated using the maximum biomass obtained over the seasons in the control treatments. These values were 1781.9 g m^{-2} for wheat, and 35.4, 44.8 and 13.4 g $plant^{-1}$ for maize, beans and peas, respectively (Table 6.5). Significant reductions in dry biomass were obtained from EC_i values of 225 mS m^{-1} for peas; 300 mS m^{-1} for beans; 150 mS m^{-1} for maize and 300 mS m^{-1} for wheat, compared to the control treatment.

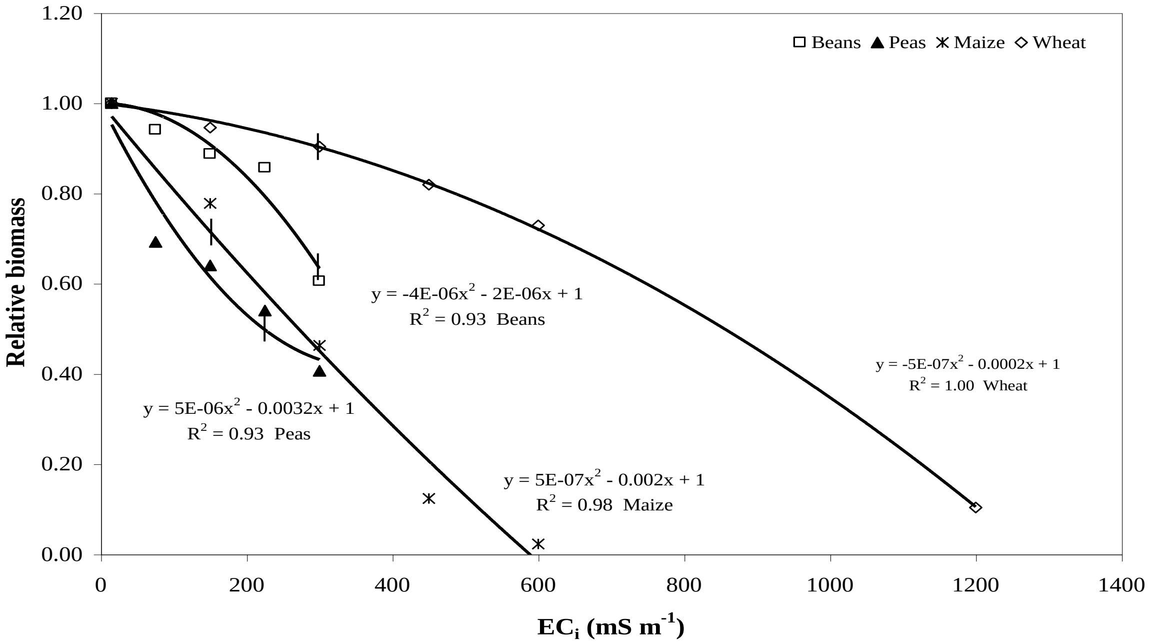


Figure 6.3 Response of relative biomass production of the selected crops to increase in different EC_i levels. The vertical line (l) indicates the onset of the first significant difference ($P \leq 0.05$) compared to the control.

The percentage reduction in biomass at the different EC_i levels, calculated from the data obtained in these experiments, has been summarised in Table 6.5. Comparing the reduction in relative biomass demonstrated that peas was the most sensitive crop in terms of biomass reduction followed by maize, beans and wheat. This tendency was valid for all EC_i levels.

Biomass of maize at 300 mS m^{-1} was reduced by 56%, while that of peas, beans and wheat were reduced by 51, 36 and 11% respectively.

Table 6.5 Relative biomass reduction (%) of selected crops at different EC_i levels

Crop	Average* (g plant $^{-1}$)	EC_i level (mS m^{-1})							
		15	**75**	**150**	**225**	**300**	**450**	**600**	**1200**
Wheat	1781.9	0	2	4	7	11	19	30	96
Maize	35.4	0	15	29	42	56	80	100	-
Beans	44.8	0	2	9	20	36	-	-	-
Peas	13.4	0	21	37	47	51	-	-	-

* Average maximum biomass for the control (15 mS m^{-1})

** g m^{-2}

The addition of salts that occurred during the growing season, resulting from irrigation, decreases the osmotic potential of the soil solution. According to Chabbra (1996) this decline in the osmotic potential decreases the plant available water because of a smaller difference between the osmotic potential of plant root cells and the sum of the osmotic and matric potential of the soil solution. As a result plants are not able to maintain their turgor, resulting in wilting. This could eventually result in the reduction in photosynthesis and eventually a reduction in biomass production. Abid *et al*. (2001) also observed a reduction in biomass production with a decrease in water quality due to salinity. Saqib *et al*. (2004a) also found that the straw weight of wheat was significantly reduced by saline conditions and this was attributed to a reduction in total biomass production. Finally, according to Munns (2002) the reduction on growth and ultimately biomass production could be ascribed to internal plant injury caused by metabolic disturbances as a result of salinity.

6.4.2.1.4 Relative seed yield

The relative seed yield of all crops, except maize which was only grown for 6 weeks, declined as a result of increasing EC_i (Figure 6.4). The actual seed yields of the control treatments, used to express the relative values were 7.6 g plant^{-1}, 25.3 g plant^{-1} and 912.2 g m^{-2} for peas, beans and wheat, respectively (Table 6.6). Significant differences were obtained from EC_i levels of 75 mS m^{-1} and 300 mS m^{-1} for beans and wheat, respectively. Using the regression coefficients, the first significant estimated reductions in relative seed yield were 29% for peas at 75 mS m^{-1}, 45% for beans at 300 mS m^{-1}, and 15% for wheat at 300 mS m^{-1} (Figure 6.4).

Table 6.6 Relative yield reduction (%) of selected crops at different EC_i levels

Crop	Average* (g plant^{-1})	EC_i level (mS m^{-1})							
		15	75	150	225	300	450	600	1200
Wheat	** 912.2	0	3	7	11	15	24	35	91
Beans	25.3	0	0	7	22	45	-	-	-
Peas	7.6	0	29	50	61	63	-	-	-

* Average maximum yield obtained at the control (15 mS m^{-1})
** g m^{-2}

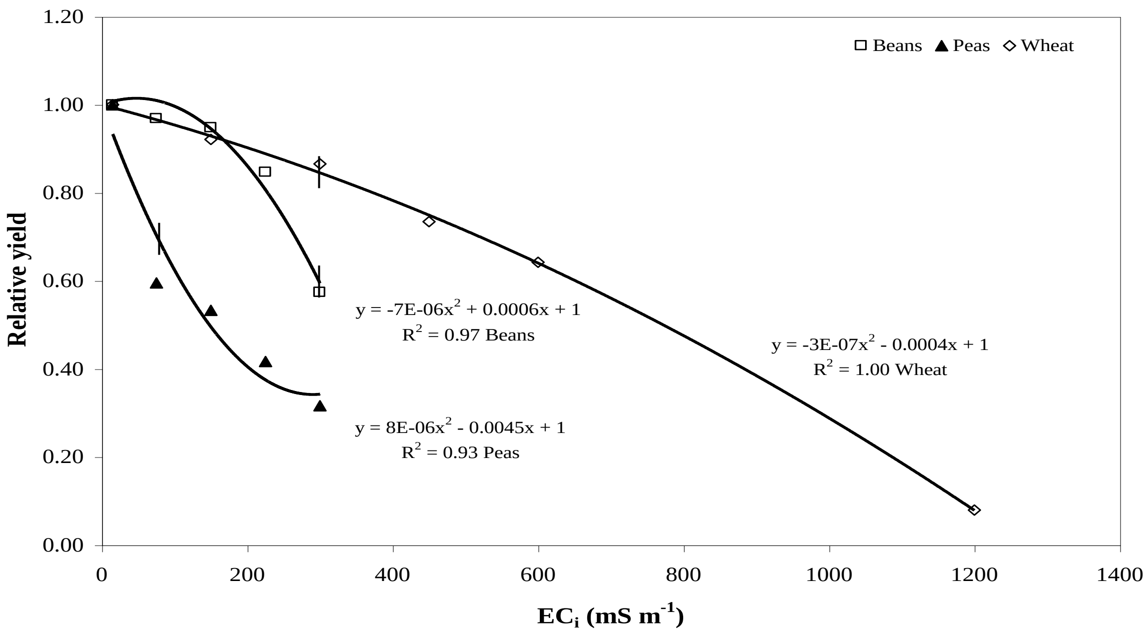


Figure 6.4 Response of relative seed yield of the selected crops to increase in different EC_i levels. The vertical line (|) indicates the onset of the first significant difference ($P \leq 0.05$) compared to the control.

Crop yield is usually markedly reduced before visual symptoms of salinity damage become apparent (Lantzke and Calder, 2000). Through salinity the formation of viable reproductive organs in annuals are affected with a reduction in the number of florets per ear, the time of flowering and ultimately the yield of cereals (El-Hendawy, Hu, Yakout, Awad, Hafiz and Schmidhalter, 2005). A recent study by Saqib *et al*. (2004a) also showed that the wheat yield was reduced as a result of a significant reduction in the number of spikelets per spike, spikes per plant and spike length. On peas and beans salinity impairs germination, inhibit nodulation, inhibits plant development and as a result reduces the final yield (Maas, 1990; Steppuhn *et al*., 2001). This phenomenon corresponds with results obtained during drought stress (Munns and Rawson, 1999). According to Saqib *et al*. (2004a) growth depression results from a water deficit, ion imbalance and ion toxicity and as a result, seed yield is significantly reduced in high saline substrate conditions.

Various soil, water and environmental factors interact to determine the salt tolerance of plants (Maas, 1990), therefore, complicating the ability to predict plant responses on an absolute basis. Thus by expressing the data on a relative basis plants can be compared to provide general salt tolerance guidelines (Maas, 1990). With regard to relative yield, it has been established that soil salinity expressed in terms of EC_e does not reduce yield significantly until a threshold has been exceeded. Beyond the threshold the reduction in yield is almost linear (Maas and Hoffman, 1977) although this was not the case in this study.

6.4.2.2 Effect of soil water salinity on growth and water use

6.4.2.2.1 Water use and salt accumulation in pots

Crop canopies grown in experimental pots tend to form a larger canopy area in relation to soil surface area, especially where long thin pots are used. Converting the total water use of the crops from ℓ pot^{-1} to mm gives apparent abnormally high values of 917, 839, 467 and 1232 mm for beans, peas, maize and wheat, respectively. This can mainly be explained by the exclusion of plant competition from adjacent plants that is normally absent in glasshouse trials in comparison to field trials. The large canopy drew water from a small surface area of the pot. This phenomenon tends to accelerate the process of salinisation in the pots. The salinisation factor can be derived from the slopes of the linear regression of EC_i versus EC_e for the different crops in Figure 6.5. Accordingly, it seems that the EC_e in the pots increased with factors of 1.9, 2.0, 2.2 and 3.2, relative to the EC_i in the maize, beans, wheat and pea experiments, respectively. It must be kept in mind that maize was only grown for 6 weeks. Water use efficiency has been expressed in g biomass per kg water applied and the results are summarised in Table 6.7.

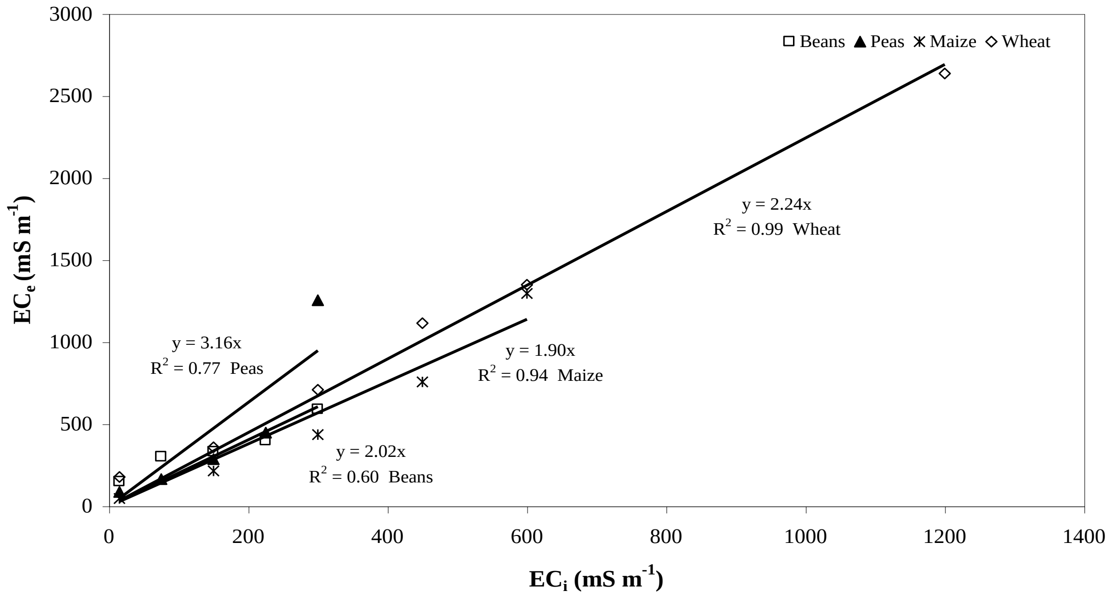


Figure 6.5 Relationship between irrigation water salinity (EC_i) and soil salinity (EC_e) in the pots.

Table 6.7 Water use efficiency (WUE), g biomass per kg water applied of the different crops in the glasshouse experiments

Crop	**Total biomass** ($g\ pot^{-1}$)	**Water applied** ($kg\ pot^{-1}$)	**WUE** ($g\ kg^{-1}$)
Beans	134.4	106.0	1.268
Peas	40.2	97.0	0.414
Maize	106.2	54.0	1.967
Wheat	206.0	142.5	1.446

6.4.2.2.2 Relative biomass

The relative biomass of the selected crops is related to EC_e as shown in Figure 6.6. The regression analysis is based on the soil water salinity levels (EC_e) and the non-stress treatments were also included in the regressions. Threshold EC_e values and that of the slopes as determined by the regression analysis are summarised in Table 6.8.

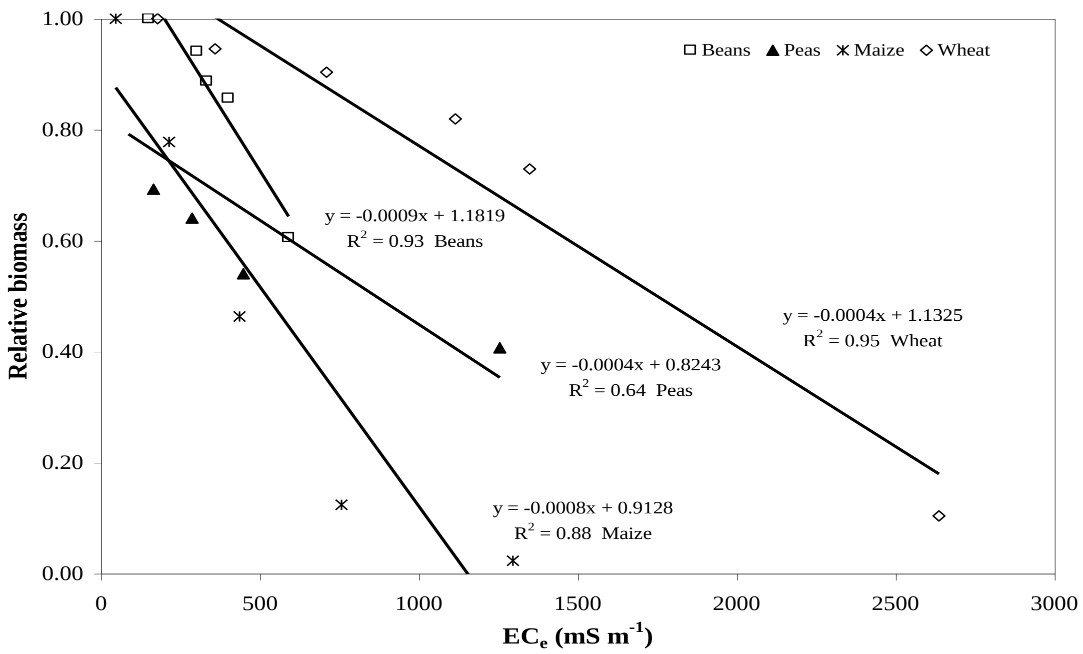


Figure 6.6 Effect of soil salinity induced osmotic stress on the relative biomass production of selected crops. Note that non-stress treatments were included in the regression.

The relative biomass of the selected crops proved to be negatively influenced with an increase in soil water salinity, as indicated by EC_e (Figure 6.6). By comparing the slopes of the regression lines it is demonstrated that beans was the most sensitive crop compared to the other selected crops with regard to soil salinity (EC_e). The slopes indicate that with an increasing in soil salinity EC_e the relative biomass was adversely affected and reduced at a constant rate that varied between 0.0004 and 0.0009 per unit EC_e for the selected crops.

Table 6.8 Threshold EC_e (mS m^{-1}) and slope values for the selected crops according to the regression analysis of the relationship between the relative biomass and soil salinity (EC_e) of the saline irrigation water treatments

Crop	Threshold EC_e(mS m^{-1})	B
Beans	202	-0.0009
Peas	*	-0.0004
Maize	*	-0.0008
Wheat	331	-0.0004

* Negative value

6.5 CONCLUSIONS

All the plant growth indicators measured proved to be negatively affected as a result of irrigation water salinity. The rate of reduction of the different indicators differed slightly but moreover larger differences were evident between the different crops as a result of differences in salt tolerance.

Quantitative and qualitative germination data revealed that though the germination percentage of beans and maize were not significantly affected, the quality of the seedlings were affected with a reduction in both the coleoptile/hypocotile and root length. This could lead to poorly established seedlings that may eventually die off as a result of primary stress (salt) or secondary stress (nutrient uptake, water uptake or susceptibility to disease), resulting in an uneven stand. Germination and seedling emergence are two indispensable parameters for the establishment of crops and are of utmost importance in crops that do not have favourable compensation ability, such as wheat.

Growth and yield indicators such as the relative leaf area, root mass, biomass and seed yield all declined with an increase in the EC_i levels. Peas proved to be the most sensitive crop, followed by beans, maize and wheat. With regard to the relative seed yield both the leguminous crops, beans and peas, were severely affected at 225 mS m^{-1} with a 22 and 61% reduction, respectively. This shows that these crops are more sensitive to saline conditions compared to the moderately tolerant crop, wheat, with a reduction of 11% at 225 mS m^{-1}.

Salts accumulated in the pots during the experiments to levels where the average electrical conductivity of the soil solution (EC_e, mS m^{-1}) was 2 to 3 times higher than that of the irrigation water (EC_i). The mean relative biomass per plant or per square meter for the replications and soils per treatment decreased linearly with increasing salinity of the soil solution.

The importance of these experiments was to quantify the effect of varying salinity levels of irrigation water (EC_i) on the establishment, growth and yield of wheat, maize, beans and peas. Furthermore, to compare the response of these selected crops to the increasing Irrigation water salinity and to determine and/or confirm at what level (EC_i) the crops showed a significant degree of reduction in growth and/or yield. Therefore, the objectives of this study were achieved.

6.6 REFERENCES

ABID, M., QAYYUM, A., DASTI, A.A. & WAJID, R.A., 2001. Effect of salinity and SAR of irrigation water on yield, physiological growth parameters of maize (*Zea Mays* L.) and properties of the soil. *J. of Res. Sci.* (Pakistan) 12, 26-33.

ABROL, I.P., YADAV, J. S. & MASSOUD, F.I., 1988. Salt affected soils and their management. FAO Soils Bulletin 39, Rome.

CHABBRA, R., 1996. Soil salinity and water quality. Balkema Publishers. Brookfield, Missouri.

CORDOVILLA, M.D.P., LIGERO, F. & LLUCH, C., 1999. Effect of salinity on growth, nodulation and N assimilation in nodules of faba bean (*Vicia Faba* L.). *Appl. Soil Ecol*. 11, 1-7.

CRAMER, G.R., SCHMIDT, C.L. &. BIDART, C., 2001. Analysis of cell wall hardening and cell wall enzymes of salt stressed maize (*Zea mays*) leaves. *Aust. J. Plant Physiol.* 28, 101-109.

BAYUELO-JIMENEZ, J., CRAIG, R. & LYNCH, J., 2002a. Salinity tolerance of *Phaseolus* species during germination and early seedling growth. *Crop Sci*. 42, 1584-1594.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY, 1996. South African water quality guidelines, 2nd ed. Volume 4. Agricultural use: Irrigation. Government Printer, Pretoria

EL-HENDAWY, S.E., HU, Y., YAKOUT, G.M., AWAD, A.M., HAFIZ, S.E. & SCHMIDHALTER, U., 2005. Evaluating salt tolerance of wheat genotypes using multiple parameters. *Europ. J. Agron.* 22, 243-253.

FSSA, 2003. Fertilizer handbook. Fertilizer Society of South Africa, Pretoria.

KATERJI, N., VAN HOON, J.W., HAMDY, A., KARAM, F. & MASTRORILLI, M., 1996. Effect of salinity on water stress, growth, and yield of maize and sunflower. *Agric. Water Manage*. 30, 237-249.

LANTZKE, N. & CALDER, T., 2000. Water salinity and crop irrigation. Farm note 46/99, Western Australia. http://agspsrv38.agric.wa.gov.au/pls

LÄUCHLI, A. & EPSTEIN, E., 1990. Plant responses to saline sodic conditions. In K.K. Tanji (ed). Agricultural salinity assessment and management. Am. Soc. of Civ. Eng., New York.

MAAS, E.V., 1990. Crop salt tolerance. In K.K. Tanji (ed). Agricultural salinity assessment and management. Am. Soc. of Civ. Eng., New York.

MAAS, E. V. & HOFFMAN, G. J., 1977. Crop salt tolerance: Evaluation of existing data. In E. H. Dregne (ed). Managing saline water for irrigation. Proceedings of the international salinity conference, Texas.

MUNNS, R., 2002. The impact of salinity stress. CSIRO division of plant industry, Australia. http://www.plantstress.com/Aricles/index.asp

MUNNS, R. & RAWSON, H.M., 1999. Effect of salinity on salt accumulation and reproductive development in the apical meristem of wheat and barley. *Aus. J. of Plant Physiol.* 26, 459 – 464.

RAMOLIYA, P.J. & PANDEY, A., 2001. Effect of salinization of soil on emergence, growth and survival of seedling of *Cordia rothii*. *For. Ecol. Manage*. 176, 185-194.

RHOADES, J.D. & LOVEDAY, J., 1990. Salinity in irrigated agriculture. In A.B. Steward & D.R, Nielsen (eds). Irrigation of agricultural crops. Agron. Soc. of Am., Madison, Wisconsin.

RICHARDS, L.A., 1954. Diagnosis and improvement of saline and alkali soils. Government Printing Office, Washington.

RUSSELL, E.W., 1973. Soil conditions and plant growth, 10^{th} edition. Longman Inc., London.

SAQIB, M., AKHTAR, J. & QURESHI, R.H., 2004a. Pot study on wheat growth in saline and waterlogged compacted soil I. Grain yield and yield components. *Soil, Tillage Res*. 77, 169-177.

SAQIB, M., AKHTAR, J. & QURESHI, R.H., 2004b. Pot study on wheat growth in saline and waterlogged compacted soil II. Root growth and leaf ionic relations. *Soil, Tillage Res*. 77, 179-187.

SHAINBERG, I. & OSTER, D., 1978. Quality of irrigation water. International Irrigation information centre: Publication no: 2, Israel.

STEPPUHN, H., VOLKMAR, K.V. & MILLER, P.R., 2001. Comparing canola, field pea, dry bean, and durum wheat crops grown in saline media. *Crop Sci.* 41, 1821-1833.

CHAPTER 7

GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Agricultural production in the arid and semi-arid areas of the world is limited by poor water resources, limited rainfall and the devastating effects associated with an excess of soluble salts. The unreliability and variability of rainfall in these areas makes irrigation a vital component of the agricultural industry globally, but also in South Africa. Irrigation in these areas is therefore inevitable in order to sustain crop production. On the other hand irrigation has lead to an increase in soil salinity due to salt accumulation. Since most of the studies on salinity and plant reaction are internationally based, it was therefore of great importance to come up with a study that is purely based on South African conditions, using four crops [wheat (cv. SST 806), maize (cv. PNR 6335), peas (cv. Solara) and beans (cv. Teebus)].

The first objective of the study was to quantify the effect of increasing irrigation water (EC_i) levels on the germination, growth and yield of selected crops. In achieving this objective, generally this study has proved beyond reasonable doubt that all plant indicators were negatively influenced, with a variation in the degree of sensitivity by an increase in the irrigation water EC levels for all crops. Interestingly these crops managed to survive even under higher soil salinities conditions than would be expected.

The second objective of this study was to compare the response of selected crops to varying EC_i levels. Generally plants are not equally affected by salinity and therefore it is important to compare the responses of different crops to increasing salinity levels of irrigation water. In order to achieve this objective only selected indicators such as leaf area, root mass, above ground biomass and seed yield were considered, because these are the primary growth indicators that determine plant performance and eventually seed yield. It was also confirmed that increasing ECi levels significantly influenced the selected indicators. The third objective was to determine at what level of irrigation water (EC_i) and soil salinity the crops show an inhibition. These crops were significantly inhibited at varying EC_i levels, depending on the salt tolerance of the crop. The relationship between biomass and EC_e was obtained in order to determine the slopes and threshold EC_e values and these were compared to literature. According to the results of the study, it can generally be confirmed that wheat was the least affected crop whereas peas were found to be the most sensitive crop, followed by beans. When expressed at an early growth stage maize showed to be very sensitive. The degree of sensitivity of these crops used in this study agrees with salt tolerance classification by Maas and Hoffman (1977), Maas (1986) and Mass (1990).

7.2 RECOMMENDATIONS

Farmers are using irrigation water without considering its quality and complain about reduced yields, therefore the following are recommended.

- Regular water analysis at all times of the year is highly recommended.
- Soil should also be regularly analysed in order to manage the soil fertility and to be able to monitor the rate of salt accumulation.
- When the irrigation water is moderately saline or continues to marginally increase in salinity, it should be considered planting crops that are moderately tolerant to tolerant. The salt tolerance of crops should be kept in mind, especially in areas where the only way to sustain crop production is by irrigating with water of marginally poor quality (saline).
- Since the pot experiments were not drained during the season, it is therefore recommended that drainage system be put in place in order to avoid unnecessary build-up of salts in the growth medium.

7.3 FUTURE RESEARCH

Salinity is a major limitation to crop production in South Africa and elsewhere in the world. The effect of salinity in crops under South African conditions should be comprehensively investigated in future. It is important to come up with salinity tolerance indices that are derived locally, using the international protocols. More crops (different cultivars) should now be brought forward for intensive evaluation. Intensive laboratory, controlled environment (glasshouse and hydroponics systems), and field trials should be conducted as long as the research opportunity is available.

CHAPTER 8

SUMMARY

Salinity is a major limitation and threat sustainable crop production in South Africa and elsewhere in the world. An intensive study by Du Preez *et al.* (2000) on the water quality of the lower Vaal River system using international salinity indicators were conducted and it was concluded that unacceptable damage to crops would be experienced if the salinity of the irrigation water continued to increase at the projected rates. Following that, intensive germination and glasshouse pot experiments were conducted based on the projected long-term salt accumulation on irrigated soils. Little or no quantitative information on the subject was available for South African conditions. This study was also part of a WRC project titled: *The effect of irrigation water salinity on the growth and water use of selected crops.*

The objective of this study was to quantify the effect of different saline irrigation water levels (electrical conductivity, EC_i) on the germination, growth and yield of selected crops, *viz.* wheat (*Triticum aestivum* L. - SST 806.), maize (*Zea mays* L. - PNR 6335), peas (*Pisum sativum* L. - Solara) and beans (*Phaseolus vulgaris* L. - Teebus) at different growth stages. These crops were subjected to five different EC_i levels (15 - control, 150, 300, 450, 600 for wheat and maize, and additionally 1200 mSm^{-1} for wheat, and 15 - control, 75, 150, 225, 300 mS m^{-1} for peas and beans). Three stages were used for each crop, *viz.* tillering, flag leaf and maturity (wheat), 2, 4 and 6 wae - weeks after emergence (maize) and 5 wae - five weeks after emergence, flowering and maturity (peas and beans).

Various morphological indicators presented on a relative scale were measured to quantify the impact of EC_i levels on both below and above ground growth. When subjecting the crops to the different EC_i levels, the salt tolerance of these plants was taken into consideration. These crops were affected at varying degrees, depending on the salt sensitivity of the crop involved. Interesting results were obtained for all the crops and based on the findings the study agreed well with the international accepted salinity classification system where wheat is classified as moderately tolerant and peas and beans as sensitive. Maize proved to be sensitive in this study, but it has to be noted that it was only at a very early growth stage.

The water use of the pot experiment plants was found to be very high and this was attributed to the smaller volume of soil relative to the canopy. All plant growth indicators proved to be negatively affected over the selected EC_i range. The reduction in growth for all crops followed a similar trend with increasing EC_i levels. The EC of the saturation soil extract (EC_e) was also measured in order to determine the rate of soil salinisation and was found to be 2 to 3 times that of EC_i. The study also compared the responses of these crops by using primary growth indicators (leaf area, root mass, biomass and seed yield) and also attempted to determine the salt tolerance values using the regression coefficients. Therefore, all the objectives set for the study were achieved. The effect of salinity on a variety of other crops under South African conditions should be thoroughly and comprehensively investigated in future.

Key words: germination, growth, yield, salinity, water quality, irrigation, wheat, maize, peas, beans

OPSOMMING

Verbrakking beperk en bedreig volhoubare gewasproduksie in Suid-Afrika en ander wêrelddele. ’n Intensiewe studie is deur Du Preez *et al*. (2000) op die waterkwaliteit van die laer Vaalrivier sisteem uitgevoer deur gebruik te maak van internasionale verbrakkings indikatore en die gevolgtrekking is gemaak dat gewasproduksie tot onaanvaarbare vlakke banadeel sou word indien die tempo van soutakkumalasie in besproeiingswater gehandhaaf word. Na aanleiding van dié studie is intensiewe ontkiemings en glashuispotproewe, gebasseer op die voorgenome langtermyn soutakkumulasie op besproeiingsgronde, uitgevoer. Weinig kwantitatiewe inligting oor die onderwerp is vir Suid-Afrikaanse toestande beskikbaar. Hierdie studie het ook deel gevorm van ’n WNK-projek, getiteld: *The effect of irrigation water salinity on the growth and water use of selected crops.*

Die doel van die studie was om die invloed van besproeiingswater met verskillende soutkonsentrasies (elektriese geleiding, EC_i) op die ontkieming, groei en opbrengs van geselekteerde gewasse, *viz.* koring (*Triticum aestivum* L. - SST 806.), mielies (*Zea mays* L. - PNR 6335), droë erte (*Pisum sativum* L. - Solara) en droëbone (*Phaseolus vulgaris* L. - Teebus) by verskillende groeistadiums, te kwantifiseer. Die gewasse is onderwerp aan vyf verskillende EC_i vlakke (15 - kontrole, 150, 300, 450, 600 vir koring en mielies, met ’n addisionele 1200 mSm^{-1} vir koring en 15 - kontrole, 75, 150, 225, 300 $mS\ m^{-1}$ vir erte en boontjies). Drie groeistadiums is vir elke gewas gebruik, *viz.* stoel, vlagblaar en volwassenheid (koring), 2, 4 en 6 wae – weke na opkoms (mielies) en 5 wae - vyf weke na opkoms, blom em volwassenheid (erte en boontjies).

Verskeie morfologiese parameters/indikatore, op ’n relatiewe skaal voorgestel, is gemeet om die invloed van EC_i vlakke op beide die ondergrondse en bogrondse groei te kwantifiseer. Die gewasse se toleransie is ook in ag geneem tydens onderwerping aan die verskillende EC_i vlakke. Die mate waartoe die gewasse beïnvloed is, is bepaal deur die gewasse se gevoeligheid. Interessante resultate is verkry vir al die gewasse en op grond van hierdie resultate het die studie goed vergelyk met bevindings van die internasionaal aanvaarde sout gevoeligheids klassifikasie sisteem waar koring as matig tolerant en erte en boontjies as sensitief geklassifiseer word. Mielies was redelik sensitief tydens die studie, maar dit is belangrik om doorop te let dat slegs op’n vroeë vegetatiewe stadium was.

Die waterverbruik van die potproefplante was besonder hoog en is toegeskryf aan die klein volume grond in verhouding tot die totale blaaroppervlakte. Alle plantindikatore is negatief beïnvloed oor die geselekteerde EC_i reeks. Die afname in groei van al die gewasse het soortgelyke tendense met 'n toename in EC_i getoon. Die EC van die versadigde grondekstrak (EC_e) is ook gemeet in 'n poging om die tempo waartoe sout in die grond akkumuleer te bepaal en daar is gevind dat die EC_e van die grond 2 tot 3 keer die van EC_i was. Tydens die studie is die verskillende gewasse se gewasreaksie ook vergelyk deur van geselekteerde plantindikatore (blaaroppervlakte, wortelmassa, biomassa en saad opbrengs) gebruik te maak. Daar is ook gepoog om die souttoleransie van die gewasse te bepaal deur van regresssie koëffisiente gebruik te maak. Daar is dus aan al die doelstellings van die studie voldoen. In die toekoms moet daar op die invloed van verbrakking op 'n verkeidenheid ander gewasse onder Suid-Afrikaanse toestande gekonsentreer en in diepte ondersoek word.

Sleutelwoorde: ontkieming, groei, opbrengs, verbrakking, waterkwaliteit, besproeiing, koring, mielies, erte, boontjies