Limitations to yield in saline-sodic soils: Quantification of the osmotic and ionic regulations that affect the growth of crops under salinity stress

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DEDICATION

I would like to dedicate this thesis to a number of people without whom I could not stand where I am today.

This thesis is dedicated to my late grandfather, who passed away at the age of 99 in the course of my Masters degree at UNE. His soul will live on within me for his encouragement and support enabling me to continue my studies in Australia.

Also this thesis is dedicated to my parents who were my first teachers and taught me the best kind of knowledge and for their love, endless support and encouragement.

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ABSTRACT

Salinity reduces yields of agricultural crops in many arid and semi-arid areas of the world where rainfall is insufficient to leach salts from the root zone. Salinity reduces plant growth and yield by two mechanisms, osmotic stress and ion cytotoxicity. Munns *et al.* (1995) proposed a two-phase model of salt injury where growth is initially reduced by osmotic stress and then by Na^+ toxicity. However, some uncertainty exists regarding the relative importance of the two mechanisms. This is due to the difficulty in separating the osmotic effect from specific ion effects because of the overlap in the development of the two type stresses during the development of salinity stress. There has also been some recent debate about the importance of soil Cl^-, and by implication plant Cl^- uptake, as predictors of damage and yield loss, rather than electrical conductivity. Where NaCl is high, increased uptake of Na^+ ions will be associated with high uptake of Cl^- ions. Reliable and effective salt tolerance screening techniques to predict field performances are important for breeding programmes. Thus, in comparisons between results from laboratory and/or glasshouse soil and solution culture screening techniques and field evaluations of salt tolerance, it is important to verify whether or not the laboratory conditions can predict responses to field stresses. The main objectives of this research were to:

- determine which of the two ions most frequently implicated in salinity, Na^+ and Cl^-, is most toxic to barley and faba bean
- quantify the relative importance of ion (Na^+ and/or Cl^-) toxicity and osmotic stress on growth and yield reduction under different levels of salinity

- investigate whether hydroponics and pot experiments under controlled environmental conditions are useful surrogates for evaluating whole-plant response to salinity under field conditions.

High concentration of Na^+, Cl^- and NaCl separately reduced growth, however the reductions in growth and photosynthesis were greatest under NaCl stress and were mainly additive of the effects of Na^+ and Cl^- stress (Chapter 5 and 6). The results demonstrated that Na^+ and Cl^- exclusion among genotypes are independent mechanisms and different genotypes expressed different combinations of the two mechanisms. The results also suggested the two-phase model of salt stress may not be appropriate at all levels of salt stress. Osmotic stress was the predominant cause of reduced growth at high levels of salinity, while specific-ion toxicity was more important under mild salinity stress (Chapters 3 and 4). In barley, the effects of salinity differed between the hydroponic and soil systems. Differences between barley cultivars in growth, tissue moisture content and ionic composition were not apparent in hydroponics, whereas significant differences occurred in soil. Reductions in growth were greater under hydroponics than in soil at similar EC values and the uptake of Na^+ and Cl^- was also greater (Chapters 3 and 7). Early assessment of salinity tolerance at seedling stage was found to be unsuitable. This work has also established sound screening procedures that significantly correlated with field evaluation of grain yield in genotypes of barley and faba bean (Chapters 7 and 8). Salt exclusion coupled with a synthesis of organic solutes were shown to be an important component of salt tolerance in the tolerant genotypes and further field tests of these plants under stress conditions will help to verify their potential utility in crop improvement programs.

Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution to Ehsan Tavakkoli and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968. The author acknowledges that copyright of published works contained within this thesis (as listed below) resides with the copyright holder(s) of those works. I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library catalogue, the Australasian Digital Theses Program (ADTP) and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

Tavakkoli E., Rengasamy P., McDonald, GK (2010) The response of barley to salinity stress differs between hydroponics and soil systems. *Functional Plant Biology* **37**, 621-633.

Tavakkoli E., Rengasamy P., McDonald GK (2010) High concentrations of Na^+ and Cl^- ions in soil solution have simultaneous detrimental effects on growth of faba bean under salinity stress. *Journal of Experimental Botany* **61**, 4449–4459.

Tavakkoli E., Fatehi F., Coventry S., Rengasamy P., McDonald GK (2011) Additive effects of Na^+ and Cl^- ions on barley growth under salinity stress. *Journal of Experimental Botany.* **62**, 2189-2203.

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