EFFECTS OF ARBUSCULAR-MYCORRHIZAL Fungal Colonization on Management of Saline Lands

Hamid Reza Asghari

Thesis submitted for the degree of

Doctor of Philosophy

in

The University of Adelaide

Faculty of Sciences

School of Earth and Environmental Sciences

The University of Adelaide

South Australia

August, 2004
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE OF CONTENTS</td>
<td>ii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xii</td>
</tr>
<tr>
<td>SUMMARY</td>
<td>xv</td>
</tr>
<tr>
<td>PUBLICATION FROM THE THESIS</td>
<td>xvii</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>xviii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>xix</td>
</tr>
</tbody>
</table>

## CHAPTER 1 - REVIEW OF LITERATURE                                      | 1    |
| 1.1 Introduction                                                       | 1    |
| 1.2 Salinization                                                       | 2    |
| 1.2.1 Definition of soil salinization                                   | 2    |
| 1.2.2 Importance of secondary salinization                             | 3    |
| 1.2.3 Classification and significance of salt-affected soils           | 5    |
| 1.2.4 Effects of salinity on soil structure                            | 7    |
| 1.2.5 Effects of salinity on plant growth                              | 8    |
| 1.2.6 Revegetation of salt-affected lands                              | 11   |
| 1.2.7 Potential for use of mycorrhizas                                 | 12   |
| 1.3 Mycorrhizal fungi                                                  | 14   |
| 1.3.1 Mycorrhizal symbiosis                                            | 14   |
| 1.3.2 Arbuscular mycorrhizas                                           | 15   |
| 1.4 Summary                                                            | 30   |
| 1.5 Aims of study                                                      | 31   |

## CHAPTER 2 - GENERAL MATERIALS AND METHODS                             | 33   |
| 2.1 Soils                                                              | 33   |
| 2.2 AM inoculum sources                                                | 33   |
| 2.3 Seed sources                                                       | 34   |
| 2.4 Surface sterilization of seeds                                     | 34   |
| 2.5 Seed germination                                                   | 35   |
2.6 Seedling production and transplantation ................................................................. 35
2.7 Growth conditions .................................................................................................. 36
2.8 Harvesting ................................................................................................................ 36
2.9 Root clearing and staining ..................................................................................... 36
2.10 Assessment of colonization ................................................................................. 37
2.11 Measurement of external hyphae ........................................................................ 37
2.12 Plant tissue phosphorus (P) determination ......................................................... 38
2.13 Assessment of soil available phosphorus ............................................................. 39
2.14 Assessment of total phosphorus in soils ............................................................. 40
2.15 Statistical analysis ............................................................................................... 40

CHAPTER 3 - MYCORRHIZAL POTENTIAL IN SEEDLING ESTABLISHMENT OF TRIFOLIUM SUBTERRANEUM UNDER SALINE CONDITIONS ......................................................................................................................... 41
3.1 Introduction ............................................................................................................. 41
3.2 Materials and Methods ........................................................................................ 43
  3.2.1 Experiment 1. Soil selection .............................................................................. 43
  3.2.2 Experiment 2. Production of matched seedlings for transplantation .............. 45
  3.2.3 Experiment 3. Effects of Glomus intraradices on Trifolium subterraneum seedling growth after transplanting at different salinity levels ...... 46
  3.2.4 Experiment 4. Effects of Glomus intraradices and P application on Trifolium subterraneum seedling growth after transplanting to different salinity levels ......................................................................................................... 48
3.3 Results .................................................................................................................... 49
  3.3.1 Results of Experiment 1. Soil selection ............................................................. 49
  3.3.2 Results of Experiment 2. Production of matched seedlings for transplantation ................................................................................................................................. 54
  3.3.3 Results of Experiment 3. Effects of Glomus intraradices on Trifolium subterraneum seedling growth after transplanting at different salinity levels ...... 56
  3.3.4 Results of Experiment 4. Effects of Glomus intraradices and P application on Trifolium subterraneum seedling growth after transplanting to different salinity levels ......................................................................................................... 69
3.4 Discussion ................................................................................................................. 80
CHAPTER 4 - EFFECTS OF MYCORRHIZAL FUNGI ON NUTRIENT UPTAKE AND ESTABLISHMENT OF A NON-RESPONSIVE MYCORRHIZAL PLANT IN SALINE CONDITIONS

4.1 Introduction

4.2 Materials and Methods

4.2.1 Experiment 1. AM responsiveness of Festuca arundinacea and Lolium multiflorum

4.2.2 Experiment 2. Effects of Glomus intraradices on Festuca arundinacea nutrient uptake and seedling establishment at different salinity levels

4.3 Results

4.3.1 Experiment 1. AM responsiveness of Festuca arundinacea and Lolium multiflorum

4.3.2 Experiment 2. Effects of Glomus intraradices on Festuca arundinacea nutrient uptake and seedling establishment at different salinity levels

4.4 Discussion

CHAPTER 5 - EFFECTS OF MYCORRHIZAL INOCULATION ON COLONIZATION AND GROWTH RESPONSES OF ATRIPLEX NUMMULARIA IN SALINE CONDITIONS

5.1 Introduction

5.2 Materials and Methods

5.2.1 Field survey. The occurrence of mycorrhizal colonization in Atriplex nummularia grown in Kalibar soil (Monarto)

5.2.2 Experiment 1. Effects of salinity stress on mycorrhizal colonization (one fungus) in Atriplex nummularia in autoclaved Ferries McDonald soil

5.2.3 Experiment 2. Effects of salinity stress on mycorrhizal colonization (mixture of six fungi) in Atriplex nummularia in autoclaved Ferries McDonald soil

5.2.4 Experiment 3. Mycorrhizal inoculum potential in Kalibar soil

5.2.5 Experiment 4. Effects of salt stress on mycorrhizal colonization in Atriplex nummularia and Trifolium subterraneum in Kalibar soil

5.3 Results
CHAPTER 6 - EFFECTS OF MYCORRHIZAL FUNGI ON MOBILITY OF PHOSPHORUS DURING LEACHING OF REPACKED COLUMNS OF A SOIL WITH LOAMY SAND TEXTURE IN SALINE CONDITIONS

6.1 Introduction ........................................................................................................... 138
6.2 Materials and methods ....................................................................................... 142
   6.2.1 Soil properties ............................................................................................... 142
   6.2.2 Experiment 1. Effects of mycorrhizal fungi on mobility of P under leaching of repacked columns of a loamy sand soil in non-saline conditions ..... 142
   6.2.3 Experiment 2. Effects of mycorrhizal fungi on mobility of P under leaching of repacked columns of a loamy sand soil in saline conditions .......... 144
6.3 Results .................................................................................................................. 145
   6.3.1 Results of Experiment 1............................................................................... 145
   6.3.2 Results of Experiment 2............................................................................... 154
6.4 Discussion ............................................................................................................. 163

CHAPTER 7 - GENERAL DISCUSSION AND FUTURE RESEARCH

7.1 Introduction ........................................................................................................... 168
7.2 Discussion .......................................................................................................... 168
7.2.1 Potential of inoculation with AM fungi to improve establishment of non-halophytic plants in saline soils and mechanisms underlying any improvement ................................................................. 168

7.2.2 Investigation of reports that increased salinity resulted in relatively high AM colonization of the halophytic chenopod *Atriplex nummularia* and potential consequences of this for plant establishment ........................................... 171

7.2.3 Roles of plants and AM fungi in influencing P leaching in soil and potential losses to ground water, under both non-saline and saline conditions ... 172

7.3 Potential advantages and constraints for application of AM fungi to revegetation of saline environments. ................................................................. 174

APPENDICES .................................................................................................. 176

REFERENCES ............................................................................................... 178
LIST OF FIGURES

Fig 1.1 Two different morphological types of AM fungi, a) Arum-type arbuscular mycorrhizal structures, b) Paris-type arbuscular mycorrhizal structures. Diagram by Dickson (1999). ..........................................................17

Fig 3.1 Experiment 1. AM colonization of Trifolium subterraneum after 2, 4 and 6 weeks planted in six soils collected from the Monarto area. CH= Camel Hill soil, K= Kalibar soil, F1= Non-calcareous Ferries McDonald soil, P1= Premimma BK horizon soil, P2= Premimma C horizon soil, F2= Calcareous Ferries McDonald soil. Vertical bars represent standard error of the means, n=4. .............................................................................................................53

Fig 3.2 Experiment 1. Shoot dry weight (SDW) of Trifolium subterraneum after 2, 4 and 6 weeks planted in six soils collected from the Monarto area. Vertical bars represent standard error of the means, n=4. .............................................................................................................53

Fig 3.3 Experiment 2. AM colonization of Trifolium subterraneum seedlings at 6-24 days after planting. Vertical bars represent standard error of the means, n=8. ........................................................................................................................54

Fig 3.4 Experiment 2. Shoot dry weights of mycorrhizal (M) and non-mycorrhizal (NM) Trifolium subterraneum seedlings at 6-24 days after planting. Vertical bars represent standard error of the means, n=8. .............................................................................................................55

Fig 3.5 Experiment 2. Shoot P concentrations of mycorrhizal (M) and non-mycorrhizal (NM) Trifolium subterraneum seedlings at 6-24 days after planting. Vertical bars represent standard error of the means, n=8. Replicate plants harvested at times from 6 to 12 days were pooled for analyses. ........................................................................................................................55

Fig 3.6 Experiment 3. Colonization of roots of Trifolium subterraneum grown in different levels of salinity at 10 (A), 20 (B) and 30 (C) days after transplanting. Vertical bars represent standard error of the means, n=3. .................................................................57

Fig 3.7 Experiment 3. Total dry weights (TDW) of mycorrhizal and non-mycorrhizal Trifolium subterraneum, at 10, 20 and 30 days (A, B and C respectively) after transplanting to different salinity levels. Vertical bars represent standard errors of the means, n=3. ..................................................................................................................58

Fig 3.8 Experiment 3. Percentage salinity responses (SR) in terms of total dry weight in mycorrhizal and non-mycorrhizal Trifolium subterraneum at the third harvest (30 days). Calculations as in Equation 1. .................................................................59

Fig. 3.9 Experiment 3. Mycorrhizal growth response (MGR) of Trifolium subterraneum in terms of total dry weight at different salinity levels and different harvests. Vertical bars represent standard errors of the means, n=3. Calculations as in Equation 2. ..................................................................................................................60
Fig. 3.10 Experiment 3. Mycorrhizal P response (MPR) of *Trifolium subterraneum* shoots (A) and roots (B) at different salinity levels and different harvests. Vertical bars represent standard errors of the means, n=3. Calculations as in Equation 3. .................................................................................65

Fig. 3.11 Mycorrhizal K response (MKR) of *Trifolium subterraneum* shoots (A) and roots (B) at different salinity in three harvests. Vertical bars represent standard errors of the means, n=3. .................................................................................66

Fig 3.12 Experiment 4. Survival of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P), grown 40 days after transplanting in soil with 2.2 (S1), 12 (S2) and 15 (S3) dS/m salinity in 3 replicates (dead plants are highlighted by circles). ............71

Fig 3.13 Experiment 4. Colonization of roots of *Trifolium subterraneum* with different treatments; mycorrhizal (M -P) and mycorrhizal with P added (M+P), grown at low and high salinity levels (2.2 and 12 dS/m, respectively) at 20 (H1) and 40 (H2) days after transplanting. Vertical bars represent standard error of the means, n=3. ...................................................................................72

Fig 3.14 Experiment 4. Total dry weights (TDW) of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal with P added (NM+P) and non-mycorrhizal without P added (NM-P), at 20 (A) and 40 (B) days after transplanting in low (S1) and high (S2) salinity levels. Vertical bars represent standard error of the means, n=3. ...................................................................................................73

Fig 4.1 Experiment 1. Total dry weights in AM inoculated and non-inoculated *Festuca arundinacea* (A) and *Lolium multiflorum* (B) after 40 and 60 days. Numbers at top of the M bars show percentages AM colonization. Vertical bars represent standard error of the means, n=4. ..........................................................91

Fig 4.2 Experiment 1. Shoot P concentrations in AM inoculated and non-inoculated *Festuca arundinacea* (A) and *Lolium multiflorum* (B) after 40 and 60 days. Vertical bars represent standard error of the means, n=4.............................93

Fig 4.3 Experiment 2. Colonization in roots of *Festuca arundinacea* grown in different levels of salinity at 20 (A) and 40 (B) days after transplanting. Vertical bars represent standard error of the means, n=4. .................................94

Fig 4.4 Experiment 2. Total dry weights of mycorrhizal and non-mycorrhizal *Festuca arundinacea* at 20 (A) and 40 (B) after transplanting in different salinity levels. Vertical bars represent standard errors of the means, n=4. ...........................................................96

Fig. 4.5 Experiment 2. Mycorrhizal P response (MPR) of *Festuca arundinacea* shoots (A) and roots (B) at different salinity levels and different harvests. Vertical bars represent standard errors of the means, n=4........................................101
Fig. 4.6 Experiment 2. Mycorrhizal K response (MKR) of *Festuca arundinacea* shoots (A) and roots (B) at different salinity levels and different harvests. Vertical bars represent standard errors of the means, n=4.

Fig 5.1. Field survey. Roots of *Atriplex nummularia* showing AM colonization in August (A), November (B) and February (C) collected from the field at Kalibar, in the Monarto area.

Fig 5.2 Experiment 1. Shoot dry weight of AM inoculated (M) and non-inoculated (NM) *Atriplex nummularia* at high and low levels of salinity at 3, 6 and 9 weeks (A, B and C respectively). Vertical bars represent standard error of the means, n=3.

Fig 5.3 Experiment 1. Ribosomal intergenic spacer amplification (RISA) agarose gel of rhizosphere communities of AM inoculated and non-inoculated in *Atriplex nummularia* grown at low (S1) and high (S2) salinity levels. S = Bacterial standard mix (Pure cultures of *Pseudomonas fluorescens*, *Bacillus amyloliquefaciens* and *B. subtilis*).

Fig 5.4 Experiment 2. Root of inoculated *Atriplex nummularia* showing internal hyphae at 6 weeks and arbuscules 10 weeks after planting.

Fig 5.5 Experiment 2. Shoot dry weight of AM inoculated (M) and mock-inoculated (NM) *Atriplex nummularia* at low or high salinity at 6 (A) and 10 (B) weeks after planting. Vertical bars represent standard errors of the means, n=4.

Fig 5.6. Experiment 2. Ordination plot of bacterial rhizosphere communities of inoculated and mock-inoculated *Atriplex nummularia* at low or high salinity generated by principal component analysis of 16S rDNA RISA banding patterns at 6 weeks (A) and 10 weeks (B) weeks after planting.

Fig 5.7 Experiment 3. Roots of *Trifolium subterraneum* colonized by AM fungi grown in non-autoclaved Kalibar soil pots at 8 weeks after planting.

Fig 5.8 Experiment 3. A single spore of AM fungi (*Glomus sp.*), trapped in a pot culture of *Trifolium subterraneum* in Kalibar soil at 8 weeks.

Fig 5.9 Experiment 4. Vesicles and hyphae in roots of *Atriplex nummularia* planted in non-autoclaved Kalibar soil at high salinity level.

Fig 5.10 Experiment 4. Shoot dry weight of *Atriplex nummularia* and *Trifolium subterraneum* at low and high levels of salinity at 10 weeks. Numbers at top of the bars shows percentages of AM colonization. Vertical bars represent standard errors of the means, n=5.

Fig 6.1 Diagram of core set-up (see text for extended description of layers and method of construction).
Fig 6.2 Experiment 1. Colonization of roots of *Trifolium subterraneum* at different depths grown in cores with different treatments; mycorrhizal (M-P) and mycorrhizal with P added (M+P), 10 weeks after transplanting. Vertical bars represent standard error of the means, n=3. ........................................146

Fig 6.3 Experiment 1. Shoot (A) and root (B) dry weights of *Trifolium subterraneum* grown in cores with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P), 10 weeks after transplanting. Vertical bars represent standard error of the means, n=3. ................147

Fig 6.4 Experiment 1. Root distribution of *Trifolium subterraneum* at different soil depths with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P). Vertical bars represent standard error of the means, n=3. ...................................................................................148

Fig 6.5 Experiment 1. Shoot (A) and root (B) P content of *Trifolium subterraneum* grown in cores with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P), 10 weeks after transplanting. Vertical bars represent standard error of the means, n=3. ................149

Fig 6.6 Experiment 1. Volume of leachate collected from cores after 10 weeks growth of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P), after irrigation with 2500 ml R.O. water in three steps (850, 1500 and 2500 ml) during 12 hours. Vertical bars represent standard error of the means, n=3. ................150

Fig 6.7 Experiment 1. Total dissolved P in leachate from cores after 10 weeks growth of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P), after irrigation with 2500 ml R.O. water during 12 hours. Vertical bars represent standard error of the means, n=3. .................151

Fig 6.8 Experiment 1. Soil available (A) and total (B) P in different soil layers from cores after 10 weeks growth of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P), after irrigation with 2500 ml R.O. water. Vertical bars represent standard error of the means, n=3. In P added treatments, P was added in the 10-13 cm layer. ............................................................................................153

Fig 6.9 Experiment 1. Percentage of root length colonized of *Trifolium subterraneum* at different depths grown in cores with different treatments; mycorrhizal (M) and mycorrhizal with P added (M+P), 8 weeks after transplanting at low (A) and high (B) salinity levels. Vertical bars represent standard error of the means, n=4. ...................................................................................156
Fig 6.10 Experiment 2. Length density of external hyphae associated with *Trifolium subterraneum* at different depth grown in cores with different treatments; mycorrhizal (M) and mycorrhizal with P added (M+P), 8 weeks after transplanting at low (A) and high (B) salinity levels. Vertical bars represent standard error of the means, n=4. In P added treatments, P was added in the 10-13 cm layer.

Fig 6.11 Experiment 2. Shoot (A) and root (B) dry weights of *Trifolium subterraneum* grown in cores with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P), at low and high salinity levels, 10 weeks after transplanting. Vertical bars represent standard error of the means, n=4.

Fig 6.12 Experiment 2. Shoot P content of *Trifolium subterraneum* grown in cores with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P), at low and high salinity levels, 10 weeks after transplanting. Vertical bars represent standard error of the means, n=4.

Fig 6.13 Experiment 2. Total volume of leachate collected from cores after 8 weeks growth of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P), in low and high salinity, irrigated with 2500 ml R.O. water during 12 hours. Vertical bars represent standard error of the means, n=4.

Fig 6.14 Experiment 2. Total dissolved P in leachate collected from cores after 8 weeks growth of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P) at low and high salinity, irrigated with 2500 ml R.O. water during 12 hours. Vertical bars represent standard error of the means, n=4.

Fig 6.15 Experiment 2. Available P in soil at different depths in cores after 8 weeks growth of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P added (NM+P), in low (A) and high (B) salinity, after irrigation with 2500 ml R.O. water. Vertical bars represent standard error of the means, n=4. In P added treatments, P was added in the 10-13 cm layer.
### LIST OF TABLES

Table 1.1 Estimate of global secondary salinization in the world's irrigated lands (Ghassemi et al. (1995) compiled from FAO data for 1987) ..................................................4

Table 1.2 Regional distribution of salt-affected soils, in million hectares (http://www.fao.org/ag/agl/agll/spush/topic2.htm) ..............................................................................6

Table 1.3 Previous reports of different effects of AM fungi on plant salinity tolerance .............................................................................................................................19

Table 1.4 Observation of mycorrhizal associations in different species of the Chenopodiaceae sampled in the field ..................................................................................................................27

Table 2.1 Digestion steps in programmed Tractor digestion block ..........................................................................................................................39

Table 3.1 Experiment 1. Some physical characteristics of six soils collected from the Monarto area (Chittleborough et al., 1976) .............................................................................51

Table 3.2 Experiment 1. Some chemical characteristics of six soils collected from the Monarto area (Chittleborough et al., 1976) .............................................................................52

Table 3.3 Experiment 3. Shoot and root nutrient concentrations of mycorrhizal (M) and non-mycorrhizal (NM) *Trifolium subterraneum* at 10 days after transplanting to different salinity levels. Means of 3 replicates ± standard error .................................................................62

Table 3.4 Experiment 3. Shoot and root nutrient concentrations of mycorrhizal (M) and non-mycorrhizal (NM) *Trifolium subterraneum* at 20 days after transplanting to different salinity levels. Means of 3 replicates ± standard error ..................................................................................................................................63

Table 3.5 Experiment 3. Shoot and root nutrient concentrations of mycorrhizal (M) and non-mycorrhizal (NM) *Trifolium subterraneum* at 30 days after transplanting to different salinity levels. Means of 3 replicates ± standard error ..................................................................................................................................64

Table 3.6 *K/Na* ratio in shoots and roots of mycorrhizal (M) and non-mycorrhizal (NM) *Trifolium subterraneum* at 10, 20 and 30 days after transplanting to different salinity levels. Means of 3 replicates ± standard error ..........................................................................................................................68

Table 3.7 Experiment 4. Shoot and root nutrient concentrations of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P (NM+P), at 20 days after transplanting to different salinity levels. Means of 3 replicates ± standard error ..........................................................................................................................77
Table 3.8 Experiment 4. Shoot and root nutrient concentrations of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P (NM+P), at 40 days after transplanting to different salinity levels. Means of 3 replicates ± standard error .................................................................78

Table 3.9 Experiment 4. K/Na ratio in shoots and roots of *Trifolium subterraneum* with different treatments; mycorrhizal (M-P), mycorrhizal with P added (M+P), non-mycorrhizal without P added (NM-P) and non-mycorrhizal with P (NM+P), at 40 days after transplanting to different salinity levels. Means of 3 replicates ± standard error .................................................................79

Table 4.1 Experiment 1. Shoot/root ratio in mycorrhizal (M) and non-mycorrhizal (NM) *Festuca arundinacea* and *Lolium multiflorum* at 40 and 60 days after planting. Means of 4 replicates ± standard error.................................................................92

Table 4.2 Experiment 2. Shoot/root ratio in mycorrhizal (M) and non-mycorrhizal (NM) *Festuca arundinacea* at 20 and 40 days after transplanting to different salinity levels. Means of 4 replicates ± standard error ...................................................................................................................................97

Table 4.3 Experiment 2. Shoot and root nutrient concentrations of mycorrhizal (M) and non-mycorrhizal (NM) *Festuca arundinacea* at 20 days after transplanting to different salinity levels. Means of 4 replicates ± standard error ...................................................................................................................99

Table 4.4 Experiment 2. Shoot and root nutrient concentrations of mycorrhizal (M) and non-mycorrhizal (NM) *Festuca arundinacea* at 40 days after transplanting to different salinity levels. Means of 4 replicates ± standard error ...................................................................................................................100

Table 4.5 Experiment 2. K/Na ratios in shoots and roots of mycorrhizal (M) and non-mycorrhizal (NM) *Festuca arundinacea* at 20 and 40 days after transplanting to different salinity levels. Means of 4 replicates ± standard error ...................................................................................................................................103

Table 5.1 Experiment 1. Shoot P concentration and content of AM inoculated and non-inoculated *Atriplex nummularia* at low or high salinity levels at 3, 6 and 9 weeks after planting. Means of 3 replicates ± standard error ...................................................................................................................................120

Table 5.2 Experiment 2. Shoot nutrient concentration of AM inoculated and mock-inoculated *Atriplex nummularia* at low or high salinity levels at 6 and 10 weeks after planting. Means of 4 replicates ± standard error .................................................................125

Table 5.3 Experiment 2. Shoot nutrient content of AM inoculated and mock-inoculated *Atriplex nummularia* at low or high salinity levels at 6 and 10 weeks after planting. Means of 4 replicates ± standard error .................................................................126
Table 5.4 Levels of significance of correlation between rhizosphere bacterial community composition and environmental variables in decreasing order of importance (eigenvalue) at 6 and 10 weeks in AM inoculated and mock-inoculated *Atriplex nummularia* at low or high salinity levels, generated by Monte Carlo Permutation test .........................................................................................................................128

Table 5.5 Experiment 4. Shoot P concentration and content of *Atriplex nummularia* and *Trifolium subtendentum* planted in non-autoclaved Kalibar soil at low or high salinity levels 10 weeks after planting. Means of 5 replicates ± standard error ........................................................................................................................................133

Table 6.1 Experiment 1. Available P budget in cores after 10 weeks growth of *Trifolium subtendentum* with different treatments; mycorrhizal without P (M-P) and non-mycorrhizal without P added (NM-P), after irrigation with 2500 ml R.O. water during 12 hours..........................................................................................................................................................152

Table 7.1 Mycorrhizal colonization in AM responsive (*T. subtendentum*) and non-responsive (*F. arundinacea*) species at low and high salinity levels in Ferries McDonald soil 60 days after planting .................................................................................................................169
SUMMARY

EFFECTS OF ARBUSCULAR-MYCORRHIZAL FUNGAL COLONIZATION ON MANAGEMENT OF SALINE LANDS

The overall aim of the research presented in this thesis was to evaluate the importance of arbuscular-mycorrhizal (AM) colonization of plants in management of saline lands. Some aspects of application of AM fungi in revegetation of saline lands are also reported.

Effects of AM pre-inoculation on mycorrhiza-responsive and non-responsive plant growth and establishment were evaluated under glasshouse conditions. The advantages of mycorrhizal fungal inoculation in increasing plant salinity tolerance and establishment in saline conditions were related to the responses of host species to AM fungi. Pre-inoculation with Glomus intraradices increased plant growth, nutrient uptake and establishment of mycorrhiza responsive Trifolium subterraneum in saline conditions, but non-mycorrhiza responsive Festuca arundinacea did not get growth benefits from AM in saline conditions.

The main mechanism underlying increased plant growth and establishment in saline conditions in mycorrhiza responsive plants was increased plant nutrient uptake, particularly phosphorus (P), at an early growth stage. The improvement could be explained by higher soil volume exploration by hyphae and/or roots, faster nutrient uptake and microbial changes in the soil rhizosphere.
AM inoculation and P application effects on salinity tolerance were compared in *Trifolium subterraneum*. Application of P increased plant growth and salinity tolerance in saline conditions, but AM inoculation increased nutrient uptake and plant salinity tolerance more efficiently than P application.

Effects of salinity on AM colonization of chenopods were investigated under glasshouse conditions. Salinity had no effects on AM colonization of *Atriplex nummularia*, but AM inoculation increased plant growth and nutrient uptake. The growth improvement was attributed to benefits from low AM colonization, and changes in bacterial community composition in the rhizosphere.

Roles of AM fungi in influencing P leaching from soil were investigated in experiments with repacked cores under both non-saline and saline conditions. Increased plant size via AM inoculation significantly decreased P leaching in the soil profile under both non-saline and saline conditions in low P soils. Increased root volume and extension external hyphal network were the main effects of AM fungi in increasing plant size under saline and non-saline conditions, which led to scavenging more P and depleting more soil available P, thereby decreasing P losses via leaching. Application of P increased plant size and decreased P leaching, but on the other hand increased soil available P and decreased AM colonization.
PUBLICATION FROM THE THESIS

DECLARATION

I declare that this thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution.

To the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of this thesis.

I consent to this copy of my thesis, when deposited in the University library, being made available for loan or photocopying.

August, 2004

Signed

Hamid Reza Asghari
ACKNOWLEDGEMENTS

My deepest thank to Sally Smith, David Chittleborough and Andrew Smith for their supervision, encouragement and support throughout the entire period of this research. I really enjoyed their constructive comments, criticisms and discussions. I would like also to express my special thank to Petra Marschner for her teaching and technical support in this study.

I particularly want to thank Colin Rivers and Debbie Miller for their excellent technical assistances. I thank other member of soil biology group of Soil and Land Systems of School of Earth and Environmental Sciences at the University of Adelaide for many valuable discussions and their friendship. Special thanks to Timothy Cavagnaro, Sandy Dickson and Jan Jansa for their technical assistance and discussions during my research.

I would like to acknowledge the University of Adelaide and Sally Smith for their financial support and providing me the opportunity to travel to Canada to attend ICOM 4 conference and travel to Spain to discuss my work with other scientists. I gratefully acknowledge Ministry of Science, Research and Technology of Iran, and Iranian Research Organization for Science and Technology for scholarship grants. Thankyou my family, I appreciate your patience and support during my study in Australia.

Finally, I wish to express my deepest gratitude to my wife, Maryam for her assistance in the lab and understanding and support during my study. Without your help I never would have been able to do this research.
To my wife