Sustainable Grazing on Saline Lands
WA2 Research Report
"Optimising the saltland pastures system for profitable use"

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"Optimising the saltland pastures system for profitable use"

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Key outcomes

Background

The growth of saltbush based saltland pastures is the major commercial use for saltland in the 300–500 mm rainfall zone of Western Australia. It has been increasingly recognised that saltbush-based pastures have limitations in terms of their nutritive value: the shrubs have high salt concentrations in their leaves, (which can limit feed intake), the digestibility is low (which limits the energy value to grazing animals), and the crude protein concentrations in the leaves can be high. These issues raise some dilemmas.

- Should we expect saltland pastures to provide all the nutrients that grazing animals need? If so, what additional plant species can be added to pastures to fill the gaps? Will animals graze the feed on offer according to their needs or according to the relative palatability of the material?
- If saltland pastures are really nutrient deficient, can we can get better use of what is available on the ground by throwing additional nutrients "over the fence"?
- If we can grow higher value plants on saltland, what should be the role of saltbush? Perhaps it really there to use water, lower water-tables and enable better under-storey to grow.
- Can we decrease the risk, targeting the planting of saltbushes and understorey into landscapes where they will grow and produce good financial outcomes for farmers?

Given these questions, we focused the WA2 SGSL project on 5 key issues:

1. We conducted preliminary examinations of the economic value of saltland pastures.
2. On saltland with little under-storey we considered the degree to which saltbushes could be supplemented by other feeds (supplementation trials).
3. On saltland with excellent under-storey, we considered the degree to which sheep would get better use of saltbush and under-storey through more intense (but brief) periods of rotational grazing (rotational grazing trials).
4. We considered the value that the saltbush plants had in lowering water-tables which would enable the better growth of higher value under-storey species (Wheel and Shoebridge trials).
5. We examined ways in which revegetation could be focused into the parts of saline landscape of highest economic value (Transect trials).

What we found

Economics. Bioeconomic modelling showed that the greatest economic gains from saltland pastures occurred when revegetation focused on salt affected land capable of growing an improved legume understorey. Gains in farm profitability came from decreased supplementary feeding and increased wool and sheep sales. The results were highly sensitive to feed quality in summer/autumn; a 10% increase would double the increment in profitability to the farm).

Supplementation. Experiments testing the benefits of supplements to sheep grazing stands of old man or river saltbush showed that grain supplements equivalent to about one third of the maintenance requirement of a sheep generally improved animal performance (liveweight, condition or wool growth), but roughage supplements did not. This has immediate implications for current recommendations for producers to graze saltbush with crop stubbles – complementarity will only exist while the animals have access to grain. Given the increasing efficiencies of harvesting operations, stubbles may therefore have little to offer.

Grazing management. Saltland pastures, consisting of widely spaced rows of saltbush with a legume under-storey were capable of supporting 7 growing sheep per hectare for 9 months of the year on mildly saline land with 330 mm annual rainfall. This stocking rate is higher than district averages for annual pastures on non-saline land. Sheep ate more saltbush when the digestibility of the under-storey was at its lowest. While there were some animal production and pasture compositional benefits to using rotational grazing, it remains unclear whether the extra effort required to manage the animals is justified by the return.

Water use. Saltbushes have a clear ability to use water. We saw a drying of the soil profile (especially in summer), and a daily pulsing in depth to water-table (especially in dense saltbush stands). However, saltbushes did not appreciably dry soil profiles if water-tables were less than 2 m from the soil surface. Our observations suggest that there may be useful landcare benefits from withholding the grazing of saltbushes in summer. Stands may also need to be supplemented with surface water management structures to handle excess water in winter.

Growth of saltbushes appears to be constrained by plant density, the availability of nutrients (especially nitrogen) and by root-zone hypoxia caused by heavy soil textures.

It can be difficult to measure soil moisture on saltland with the neutron moisture meter because low counts can be caused either by low moisture or high concentrations of chloride. We have considered this issue on a commercially managed stand of old man saltbush at Lake Grace in which chloride was a clear confounding factor. Comparisons of bores 13 m inside a saltbush stand with bores 13 m outside the saltbush stand showed that the saltbushes lowered water-tables by 16 cm in summer. Our best estimate of stored soil moisture suggested that the saltbushes dried out soil profiles by 50 to 150 mm compared with annual pastures.

Locating plants in the saline landscape. The growth of saltland pasture species is affected by two highly variable soil conditions – salinity and waterlogging. Our work suggests that reasonable predictions can be made about the success of perennials based on the bulk conductivity of the soil over the upper 50 cm and the depth to the water-table. It may therefore be possible to base saltland capability assessment substantially on an EM38 survey and a backhoe pit to determine the depth and salinity of the groundwater and the soil texture.

Conclusion. There is broad consensus across SGSL projects that currently available commercial options for farmers in the 300-500 mm rainfall zone of Western Australia can be summarised as indicated in Figure 1. The key principles are:

1. Saltland can be divided into land of different capabilities.
2. *Severely affected land* (~50% of the total) will grow samphire species and should be fenced and not used for grazing.
3. Moderately affected saltland (30-40% of the total) will grow dense stands of saltbush (~1,000 stems/ha) with small amounts of low value under-storey. This land can be used for grazing – the maintenance of livestock during feed gap periods – but energy supplements will need to be provided and the profitability of the systems will be low.
4. Mildly affected land (~10-20% of all saltland) will grow alleys of saltbush with highly productive annual legume under-storey. This land can be used for the grazing of growing sheep, energy supplements will rarely be required and the profitability of the systems will be high.
5. The use of green perennial vegetation in the landscape (like saltbush) will help dry soil profiles, lower water-tables and maintain the systems in their

most productive condition. Given that saltland is located in the lowest parts of the landscape and subject to inundation, plantings may need to be supplemented with some engineering works to control excess water flows.

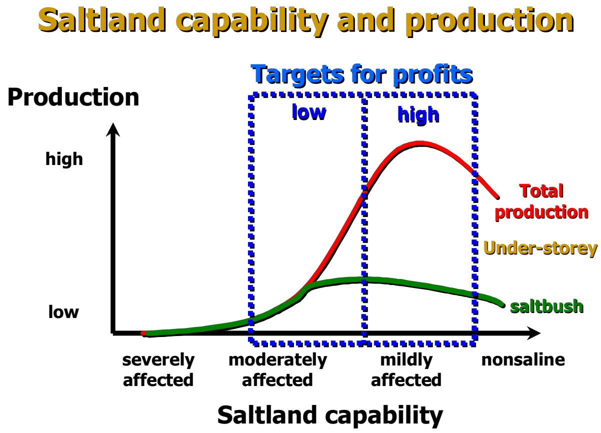

Figure 1. Saltbush-based saltland pastures in the 300-500 mm rainfall zone of WA – capability, production and profitability.

Where we want to go next

Land capability assessment. Given the consensus view discussed above, the first priority that we face will be to devise a robust means of assessing saltland capability. The Transect experiments have made a good start in this direction but more needs to be done.

Mildly affected saltland. There needs to be a further sustained effort on this potentially profitable land. The key issues will be:

- Improving the salt and waterlogging tolerance of under-storey legumes.
- Improving all aspects of establishment and management so that the systems operate optimally.

Moderately affected land. Some work should continue on the land capable of growing saltbush without an under-storey. The key issues here are:

- Improving the nutritive value of saltbush. Saltbushes are currently derived from wild populations. Gains in their nutritive value may decrease the requirements for energy supplementation.
- Supplementation. The benefits of good quality hay have not yet been determined.

Presentations at Field days, technical workshops and as papers

The SGSL WA2 team has had a wonderful collaborative relationship with its farmer collaborators, with the staff and supporters of the WA1 and Producer Network projects and with the wider family of collaborators within the CRC for Plant-based Management of Dryland Salinity. It is often difficult to separate out the extension activities of the various Western Australian team members as being particular to one or other of the projects. What can be said is that we have had an integrated sustained extension push through the life of the project through farmer field days and workshops, technical scientific workshops at the local, national and international level, and through the media. Many of our field days have been jointly badged with the Saltland Pastures Association of WA Inc.

Farmer groups

- October 2002 – Badgingarra Landcare Group. Ed Barrett-Lennard gave presentation entitled “Excess water – risk or opportunity”.
- October 2002 – Watheroo Landcare Group. Ed Barrett-Lennard gave presentation entitled “Saltland pastures: today’s story.”
- July 2003 – SGSL research and producer network tour. Ed Barrett-Lennard, Robyn Dynes, Hayley Norman and Kim Melvin spoke about the first year of grazing data at the Yealering site. (40 farmers, researchers and Producer Network coordinators).
- September 2003 - Saltland Pastures Association Annual Field Day. Robyn Dynes, Ed Barrett-Lennard and Darryl McClements spoke to 52 farmers about the first year of grazing data from the Yealering site and the demonstration strips.
- November 2003 – field day at Yealering.
- March 2004 – field day at Pingaring.
- March 2004 – Mingenew Irwin Group. Ed Barrett-Lennard gave a presentation entitled “Saltland pasture production”. About 40 farmers present.
- April, May 2004 – Farming for a Future Conference, Albany. Ed Barrett-Lennard, Hayley Norman and Dave Masters gave a presentation entitled “The Saltland Pasture Revolution”. (80 farmers). The same talk was also delivered at Wongan Hills (10 farmers) and Walletin Creek (30 farmers).
- September 2004 – field day at Meckering.
- September 2004 – presentation to Saltland Pastures Association AGM.
- October 2004 – Northern Agriculture Catchment Council, Three Springs. Ed Barrett-Lennard presented on “Nailing our colours to the mast: Strategies for future saltland systems”. About 20 farmers present.

- October-November 2004 – SGSL Producer Network “Roadshow”. WA2 team members presented at 3 field days at Wubin, Cranbrook, and Wickepin. Attendance ~100 farmers and extension agents.
- March 2005 – field day at Yealering.
- April 2005 – SGSL/SPA Roadshow, Kellerberrin. Ed Barrett-Lennard with Richard George, Greg Hamilton, Hayley Norman and Dave Masters presented on “Nailing our colours to the mast: strategies for future saltland systems”.
- July 2005 – Fitzgerald Biosphere Group, Bremer Bay. Ed Barrett-Lennard gave a presentation entitled “Integrated solutions for valley floors in WA”. About 20 farmers present.
- September 2006. WANTFA field day at Meckering. Also had field trip visit from the Australian Agronomy Conference. (40 people)

Local Workshops

The following lists give an indication of the commitment of the project to selling its message to other workers at the technical level and to the broader community. The presentations given by Hayley Norman (reported in the WA1 project’s final report) should also be recognised as part of the activity of the present project.

- August 2002 – Local SGSL team meeting, South Perth. Ed Barrett-Lennard gave a presentation entitled “Optimising saltland pastures”.
- November 2002 – SGSL Workshop Cowra NSW. Ed Barrett-Lennard gave presentation entitled “WA2 – a brief overview”.
- November 2002 – CRC WA Node meeting, University of WA. Ed Barrett-Lennard gave presentation entitled “Sub-program 8 – a brief overview”.
- December 2002 – CRC Sub-program meeting, Canberra. Ed Barrett-Lennard gave presentation entitled “WA2 proposal for SGSL”.
- March 2003 – Seminar to School of Plant Biology, UWA. Ed Barrett-Lennard gave presentation entitled “The joy of mixtures: can we really make saltland pastures work”.
- May 2003 – Inaugural SGSL WA2 project meeting, Narrogin. Ed Barrett-Lennard gave presentation entitled “Welcome to the first meeting of the WA2 team”.
- August 2003 – Seminar to URS International. Ed Barrett-Lennard gave presentation entitled “Productive use and rehabilitation of saline land: making dollars from disaster”.
- August 2003 – Sheep Updates Perth. Robyn Dynes, David Henry, Hayley Norman and David Masters presented a paper entitled ‘Feeding value – the

essential link between pastures and animals'. Ed Barrett-Lennard presented a paper entitled "Pastures for saline land".

- August 2003 – NRM managers meeting, WA Department of Agriculture. Ed Barrett-Lennard gave a presentation entitled "Project overview and productive use of saline land".
- September 2003 – Training WADA staff and SGSL Producer Network members. Hayley Norman and Matt Wilmot provided training into techniques for shrub forage estimation. Hayley Norman also presented a seminar on the feeding value of saltland pastures.
- October 2003 – State Landcare Conference. Ed Barrett-Lennard and Hayley Norman presented a presentation entitled 'Saltland pastures – increased profits flow from mixtures'.
- October 2003 – SGSL State Workshop, Bentley. Ed Barrett-Lennard gave presentation on "Achieving the best establishment and production on your saltland pasture".
- November 2003 – Workshops for Landmark consultants, Dalwallinu and Katanning. Ed Barrett-Lennard presented a talk entitled "Saltbush pastures, salt/waterlogging interactions and the vision thing" to both groups.
- January 2004 – Review of grazing trials at CSIRO Floreat. Ed Barrett-Lennard presented on "Agronomic trials".
- February 2004 – CRC review, Adelaide. Ed Barrett-Lennard presented on "Agricultural systems for valley floors: two fragments".
- March 2004 – SGSL internal review, CSIRO Floreat. Ed Barrett-Lennard presented on "WA2 project: background, present results and future directions."
- March 2004 – SGSL workshop, Adelaide. Ed Barrett-Lennard presented on "WA2 project: background, present results and future directions."
- April 2004 – Workshop with CRC LEME, Bentley. Ed Barrett-Lennard presented on "Sustainable grazing of saline lands: the big picture and a few results".
- May 2004 – Department of Agriculture ARM Project Meeting, South Perth. Ed Barrett-Lennard presented on "SGSL WA2 Project".
- October 2004 – CRC Program 4 meeting, Katanning. Ed Barrett-Lennard presented on "Systems for discharge landscapes"
- December 2004 – Perennial Shrub Grazing Systems Workshop Adelaide. Ed Barrett-Lennard, Hayley Norman and Dave Masters gave a presentation entitled "Improving the nutritive value of saltbush: work with clones and grazing studies suggest a way forward".
- December 2004 – Landmark extension staff. Ed Barrett-Lennard, Hayley Norman and Dave Masters, Richard George and Greg Hamilton gave a

presentation entitled “The need for changes to whole farming systems in the valley floors: background and options”.

- May 2005 – 3rd Year pasture students at UWA. Ed Barrett-Lennard presented two lectures on “Saltland agronomy” and “Saltland farming systems”.
- May 2005 – Wesley College, Science Fair. Ed Barrett-Lennard presented on “Salinity and the future”. About 100 Year 8 students.
- May 2005 – NRM Conference, Perth. Ed Barrett-Lennard presented on “An integrated solutions approach to Catchment Water Management – especially the wet bits”.
- July 2005 – SGSL Producer Network committee meeting. Ed Barrett-Lennard gave a presentation on “WA2 – the big picture issues”.
- July 2005 – Sheep updates, Perth. The team (Ed Barrett-Lennard, Hayley Norman, Matt Wilmot, Meir Altman, Kelly Pearce, Sally Phelan, and Dave Masters) presented a paper “Saltland Pastures: dispelling some myths”.
- August 2005 – Eyre Peninsula, South Australia. Ed Barrett-Lennard visited the region and gave a presentation entitled “Thinking about five questions”.
- August 2005 – SGSL National Workshop, Orange. On behalf of the WA2 team Ed Barrett-Lennard presented on “WA2 summary”.
- August 2005 – Old man saltbush improvement workshop – Ed Barrett-Lennard presented on “Adventures and observations on the plausibility of selecting better saltbush”.
- October 2005 – SGSL Producer Network Workshop, Bassendean. Ed Barrett-Lennard wrapped up the day with a presentation entitled “The Harvey Jones Story (a hypothetical case study on saltland pastures)”
- March 2006 – 3rd Year pasture students at UWA. Ed Barrett-Lennard presented two lectures on “Saltland agronomy” and “Saltland farming systems”.
- April 2006 – Hydrology theme workshop, University of WA. Ed Barrett-Lennard and Meir Altman presented on “What the pasture people want from the hydrology theme”.
- May 2006 – Lecture to Murdoch University students. Ed Barrett-Lennard, Meir Altman and Hayley Norman presented on “Saltland rehabilitation”.
- September 2006 – SGSL National Workshop, Ballarat. Ed Barrett-Lennard presented a report on the WA2 project on behalf of the team.
- October 2006 – CRC WA Node Meeting. Ed Barrett-Lennard presented on “Saltland pastures: plants and sites”.

National and International Workshops

- February 2003 – Agronomy Conference, Melbourne. Hayley Norman spoke about the botanical diversity of saline areas.
- October 2003 – PURSL Conference at Yeppoon. Ed Barrett-Lennard delivered WE Wood Memorial Lecture entitled "Thinking about productive systems on saltland: some fragments and the big picture". The lecture was subsequently repeated to a local WA audience.
- June 2004 – International Workshop, Dubai. Ed Barrett-Lennard spoke on "Saltland Pastures in Australia: Making Dollars from Disaster". This talk was presented again several days later to the Ministry of Agriculture in Oman.
- July 2004 – SGSL National Forum, Adelaide. Ed Barrett-Lennard and Hayley Norman presented on "WA2 project: a few bits and pieces".
- August 2004 – Salinity Solutions Conference, Bendigo. Ed Barrett-Lennard, Richard George, Greg Hamilton, Hayley Norman and Dave Masters present a paper entitled "Multi-disciplinary approaches suggest profitable and sustainable farming systems for valley floors at risk of salinity". This presentation was a given a second time to the Saltland Pastures Association AGM in September 2004.
- September, 2004 – International Society of Plant Anaerobiosis Conference, Perth. Ed Barrett-Lennard presents a paper entitled "The interaction between waterlogging and salinity: implications for plant survival, growth and ecological zonation on saltland".
- April 2005 – International Salinity Forum, Riverside, USA. Ed Barrett-Lennard, Dave Freudenberger and Hayley Norman presented a paper on "Composition, structure and function in saltland ecosystems: blueprints and parts for saltland restoration". Ed also presented a poster of behalf of Australia's producer network entitled "Australia's sustainable grazing on saline lands initiative: creating attitudinal change on a grand scale".

Media

The following lists give an indication of the commitment of the project to selling its message in the media. The media work done Dr Hayley Norman (reported in the WA1 project's final report) should also be recognised to some degree as emenating from the present project.

- September 2003. Media article about the Yealering Research Site, entitled 'Saltbush plantings lead to better use of waste products' (*Farm Weekly*, 11 September, pages 118–119).
- October 2003 – Substantial media attention was given to the publication of the second edition of 'Saltland Pastures in Australia: A Practical Guide'.

- January 2004. Media article about the Yealering Research Site, entitled 'Beating the Autumn feed gap with saltbush in Yealering' (*Farm Weekly*, 8 January, pages 69–71).
- March 2004 – Media article featured the 'Wheel' experiment at Carter's farm at East Wubin (*Salt Magazine*).
- April 2004 – Landline interview (television) recorded with Joanne Shoebridge at the Pingaring research site.
- September 2005 – SGSL Pride in Saltland Management Photo Competition. Ed Barrett-Lennard and Hayley Norman's submitted photos that were accepted by the national exhibition. Ed was the "Science in Saltland" category winner.

Technical publications

The project team have been active in extending new knowledge to producers. Much of this activity has been in collaboration with members of the SGSL WA1 project. Some of the technical publications are listed below.

In addition the team have provided research updates for almost every edition of the newsletter of the Saltland Pastures Association and the CRC salinity internal newsletter. There has also been a considerable effort in assisting with articles in 'Focus on salt', 'Salt' magazine and the soon to be released SALTDECK book.

Thomas D.T., **Norman H.C** and Filmer, M. (2006). Measuring diet selection accurately. Farming Ahead, Kondinin Group, December, 2006.

Wilmot, M.G and Norman, H.C. (2006). Saltbush more hardy than many think. Farming Ahead, Kondinin Group, October 2006

Norman H., Revell D.K., Masters D.G. (2006) Animal production from extensive grazing systems – factors contributing to productivity, saltland pastures and incorporating shrubs into systems. Regional Sheep & Beef Updates. 25-26 July 2006.

Norman, H.C and Wilmot, M. G. (2006). Maximising animal production from saline land. Annual grazing field day booklet, Mingenew-Irwin producer group, Geraldton, May 2006

Barrett-Lennard E., Norman, H., Wilmot, M., **Altman, M.,** Pearce, K., Phelan, S., Masters, D. (2005). Saltbush pastures: dispelling some myths, Western Australian Sheep Updates 2005

Norman, H., Silberstein, R. Atkins, L., **Wilmot, M**., **Barrett-Lennard, E.** and Nichols, P. (2005). Profitable and sustainable grazing on saline lands In WA – site 1 and 2. Booklet produced for Lake Grace Field Day.

Norman, H., Silberstein, R. Atkins, L., **Wilmot, M.**, **Barrett-Lennard, E**. and Nichols, P. (2005). Profitable and sustainable grazing on saline lands In WA – site 1 and 2. Booklet produced for Yealering Field Day.

Norman, H., Silberstein, R. Atkins, L., **Wilmot, M., Barrett-Lennard, E**. and Nichols, P. (2005). Profitable and sustainable grazing on saline lands In WA – site 1 and 2. Booklet produced for AWI/SGSL field tour.

Dynes, R., Henry, D. **Norman, H.** and Masters, D. (2003). Feeding value – the essential link between pastures and animals. Agribusiness Sheep Updates, Perth 12-13 August 2003.

Barrett-Lennard, E.G. (2003). Pastures for saline land. Agribusiness Sheep Updates, Perth 12-13 August 2003.

Dynes, R. Norman, H. and Masters, D. (2003). Maximising livestock production from saltland pastures. SGSL Producer network: Farmers with Researchers. Sustainable Grazing on Saline Lands Forum, Perth October 2003.

Norman, H.C., Dynes, R.A. and Masters, D.G. (2003). Optimising saltland pasture systems for profitable use – energy supplementation. Handout prepared for CRC Node visit to Yealering Research site (November 2003).

Masters, D.G., **Norman, H.C and Dynes, R.A.** (2002). A mix of plants lifts feed value from saline land. Farming Ahead, Kondinin Group, October 2002.

Books

Barrett-Lennard, E.G., Malcolm, C.V. and Bathgate, A. (2003). *Saltland Pastures in Australia – a Practical Guide*, Second Edition. Sustainable Grazing of Saline Lands (a sub-program of Land, Water and Wool), 176 pp.

Papers in refereed scientific journals

Norman, H.C. and Masters, D.G. (2006) Animal production from extensive grazing systems. In *Perennial Pastures Guide* Ed G. Moore. (in press).

Barrett-Lennard, E. and Moore, G. (2006). Saltland pastures. In *Perennial Pastures Guide*. Ed G. Moore. (in press).

Masters D.G., Benes S.E. and **Norman H.C**. (2006). Biosaline agriculture for forage and livestock production. *Agriculture, Ecosystems and Environment* (in press)

Stevens, J.C., **Barrett-Lennard, E.G.** and K.W. Dixon, K.W. (2006). Enhancing the germination of three fodder shrubs (*Atriplex amnicola*, *A. nummularia, A. undulata*; Chenopodiaceae): implications for the optimisation of field establishment. *Australian Journal of Agricultural Research,* **57** (in press).

Barrett-Lennard, E.G., George, R.J., Hamilton, G., **Norman, H**. and Masters, D. (2005). Multi-disciplinary approaches suggest profitable and sustainable farming systems for valley floors at risk of salinity. *Australian Journal of Experimental Agriculture*, **45**, 1415–1424.

Rogers, M.E., Craig, A.D., Munns, R.E., Colmer, T.D., Nichols, P.G.H., Malcolm, C.V., **Barrett-Lennard, E.G.,** Brown, A.J., Semple, W.S., Evans, P.M., Cowley, K., Hughes, S.J., Snowball, R., Bennett, S.J., Sweeney, G.C., Dear, B.S. and Ewing, M.A. (2005). The potential for developing fodder plants for the salt-affected areas of southern and eastern Australia: an overview. *Australian Journal of Experimental Agriculture*, **45**, 301–329.

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Masters, D.G. Rintoul, A.J. Dynes, R.A., Pearce K.L. and **Norman, H.C**. (2005). Feed intake and production in sheep fed diets high in sodium and potassium. *Australian Journal of Agricultural Research* 56, 427-434.

Norman, H.C., Friend, C., Masters, D.G, Rintoul, A.J., **Dynes. R.A**. and Williams, I. H. (2004) Variation within and between two saltbush species in plant composition and subsequent selection by sheep. *Australian Journal of Agricultural Research*, 55, 1-9.

Barrett-Lennard, E.G. (2003). The interaction between waterlogging and salinity in higher plants: causes, consequences and implications. *Plant and Soil*, **253**, 35–54.

Malcolm, C.V., Lindley, V.A., O'Leary, J.W., Runciman, H.V. and **Barrett-Lennard, E.G.** (2003). Halophyte and glycophyte salt tolerance at germination and the establishment of halophyte shrubs in saline environments. *Plant and Soil*, **253**, 171–185.

Papers in published conference proceedings

Wilmot M.G. and Norman H.C. (2006). Saltbush biomass in a saline grazing system - use it or lose it. Animal Production in Australia, 26

Thomas D.T., **Norman H.C.,** Rintoul A.J., **Wilmot M.G.,** Masters D.G. (2005) The use of stable carbon isotopes to measure diet selection in sheep grazing saltland pastures. In 'Horizons in livestock sciences: Redesigning animal agriculture'. CSIRO Livestock Industries. Gold Coast, Australia 2-5 Oct 2005. p. 29.

Edwards, N.J**., Norman, H.C**., Barrett-Lennard, E.G., Hebart, M.L., McCaskill, M.R., King, W.M. and Mason, W. (2005). Sustainable Grazing on Saline Lands: Profitable and sustainable grazing systems for livestock producers with saline land in southern Australia. In 'Horizons in livestock sciences: Redesigning animal agriculture'. CSIRO Livestock Industries. Gold Coast, Australia 2-5 Oct 2005.

Norman H. C., Dynes R. A., and Masters D. G. (2005) Diversity and variation in nutritive value of plants growing on 2 saline sites in south-western Australia. In 'Satellite Workshop of the XXth International Grasslands Congress (Pastoral systems in marginal environments)'. Glasgow, Scotland

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Jenkins, S., **Barrett-Lennard, E.G.** and Rengel, Z. (2005). Ecological zonation of tall wheatgrass and puccinellia caused by the interaction of salinity and waterlogging? In: *Proceedings of the International Plant Nutrition Colloquium*, Beijing.

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Part 2 – Papers

Weight changes and wool production of weaner sheep grazing old man or river saltbush supplemented with grain, hay or straw.

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Practical implications to industry

- Saltbush dominant stands, on a moderately saline site in the low to medium rainfall bet of south-western Australia, provided from 496 to 650 grazing days/ha.year for 11 month old sheep during autumn/early winter. Wool growth ranged from 2.5 to 9.3 kg clean wool/ha.
- The saltbush produced between 400 to 700 kg of 'edible' (leaves and stems < 3mm) DM/ha.year. The nutritive value of the edible biomass was low in energy but contained moderate crude protein. The volunteer understorey provided up to 1500 kg DM/ha.year of which approximately 500 kg DM/ha was available in autumn. The energy and protein value of this material varied across species but was generally poor.
- Energy supplements of 175 g barley/day (approximately one third of the maintenance requirement of the sheep) generally improved animal performance in terms of liveweight, condition and wool growth. The next step in this research area is to determine the optimal levels of grain supplementation and types of grains to use.
- Although not tested in this project, supplementation of animals in saltbush plots over autumn may offer returns beyond the feeding value of the saltland pasture, examples include; less compaction of more productive soils, a break in intestinal worm cycles and allowing pastures to achieve optimal growth in the early stages of pasture growth.
- In this experiment, roughage supplements did not improve animal performance in terms of liveweight, condition or wool growth. We do not know if high quality hays will improve animal performance.
- This has immediate implications for the current recommendation for producers to graze saltbush with crop stubbles. Complementarity between stubbles and saltbush will only exist while the animals have access to grain. Given increasing efficiencies of grain harvesting machines stubbles may have little to offer for saltland grazing.
- The saltbush plots contained high levels of plant diversity and several native perennial plants.

Introduction

Old man saltbush (*Atriplex nummularia*) and river saltbush (*A. amnicola*) species are widely used in commercial grazing systems on saline land in south-western Australia. In a Mediterranean-type climate, saltbush provides green feed in autumn when annual pastures are dead and feed is scarce (Masters *et al* 2001). Being both perennial and active through the summer/autumn period, saltbushes have the potential to reduce leakage of rainwater to water tables thus alleviating the effects of dryland salinity (Barrett-Lennard *et al* 2005). There is some debate however that saltbush-based pasture may not produce enough feed of sufficient quality to justify costs of establishment for livestock systems.

Although old man and river saltbushes are two of the most commonly planted species in Western Australia, there have been no studies that compare their biomass production, feeding value and only few that compare nutritive value. Nutritive value is defined as the animal production response per unit of feed intake (Uylatt 1973), and is often predicted using laboratory (*in vitro*) techniques. Although more difficult to measure, feeding value offers a better comparison of the value of saltbush species and is the sum of both nutritive value and the factors that voluntary influence intake. Variation in voluntary feed intake accounts for at least 50% of the variation that is observed in feeding value of forages (Ulyatt 1973). Voluntary feed intake is not easy to predict, specific animal influences include; gut fill (Weston 1996), clearance rate of digesta from the rumen (influenced by digestibility), energy, protein content, palatability, feeding behaviour (time spent grazing, bite mass and bite frequency), animal species and physiological state of the animal. Plant morphology may also play a role, for example, browsing from sparse, spiny shrubs is more time consuming for animals than eating from a dense sward.

Based on *in vitro* nutritive value data from past studies, old man saltbush appears to have higher energy and protein and higher levels of anti-nutritional compounds than river saltbush. Norman *et al.* (2004) compared the *in vitro* nutritive value of river and old man saltbushes growing together on a saline site, and found that river saltbushes had higher acid detergent fibre (ADF - 25.8% compared to 17.5 %), higher neutral detergent fibre (NDF - 40.9% compared to 30.9 %), lower pepsin-cellulase digestibility of organic matter in the dry matter (P-CDOMD - 52% compared to 60%) and lower crude protein (CP – 9% compared to 14%) than old man saltbushes. These differences in *in vitro* nutritive value suggest that the feeding value of old man saltbushes should be higher than that of river saltbushes. The old man saltbushes however had significantly higher soluble salt in the leaves (22% compared to 20%), higher sulphur (0.46% compared to 0.39%) and higher nitrates (173 mg/kg dry matter compared to 95 mg/kg dry matter) than river saltbushes. These levels of salt and sulphur are higher than the levels recommended for ruminants and could lead to reduced voluntary feed intake (National Research Council 2005; Bird 1972; Norman *et al.* 2004, Masters *et al.* 2006).

When given a choice sheep preferred to eat river saltbush before old man saltbush (Norman *et al*. 2004). There is a considerable body of literature to suggest that feed selection by ruminants is not random and that they select a diet that is higher in digestible nutrients and lower in toxins than the average of plant material on offer (Provenza 1995, Forbes and Mayes 2002). The findings by Norman *et al.* (2004) suggested that the higher *in vitro* nutritive value of old man saltbush is not enough incentive to override the anti-nutritional considerations. Also, other factors influencing intake such as shrub architecture, availability of biomass and palatability could be influences selectivity by sheep. The first hypothesis tested in this experiment is that sheep grazing river saltbush will be heavier and grow more wool than sheep grazing old man saltbush, most likely due to differences in feed intake and the impact of anti-nutritional compounds rather than energy or protein.

A number of studies, both Australia and overseas, question the feeding value of saltbushes. Factors limiting feeding value can be grouped into 4 categories. Firstly, biomass production from saltbushes growing on saline land (rather than non-saline land irrigated with saline water) can be as poor as 0.48 to 0.92 t/ha of 'edible' dry matter (leaves and stems < 3mm) (Warren *et al.* 1994, Wilmot and Norman 2006). Secondly, reported *in vivo* organic matter digestibility of saltbush forage grown without irrigation in Australia ranges from 30 to 66%, with many studies demonstrating that saltbush has energy values below maintenance for mature, dry sheep (Wilson 1966, Warren *et al.* 1990). Thirdly, salt accumulation in the leaves of saltbushes results in ash levels in the forage ranging from 15 to 27% (Warren *et al.* 1990, Norman *et al.* 2004). These levels of salt depress both feed intake and digestibility of the feed (Masters *et al.* 2005). Sheep will stop eating salty forage after they have ingested approximately 200g salt/day (Masters *et al.* 2006). This means that if the 'edible' component of a saltbush shrub has 25% ash in the dry matter and has an *in vivo* organic matter digestibility of 50%, a 50kg mature wether will stop eating after ingesting about 800g of biomass, 250 g short of the 1050g of predicted biomass required to maintain liveweight (Masters *et al.* 2006, Freer *et al.* 1997). Finally, saltbushes contain a range of minerals and secondary compounds, such as sulphur, nitrates and oxalates, at concentrations that can have a detrimental effect on animals (Leigh 1986, Masters *et al.* 2001, Norman *et al.* 2004). The inability of sheep to maintain liveweight when grazing predominantly saltbush biomass has been demonstrated by Wilson (1966), Pol (1980), Warren and Casson (1992) and Morecombe *et al.* (1996).

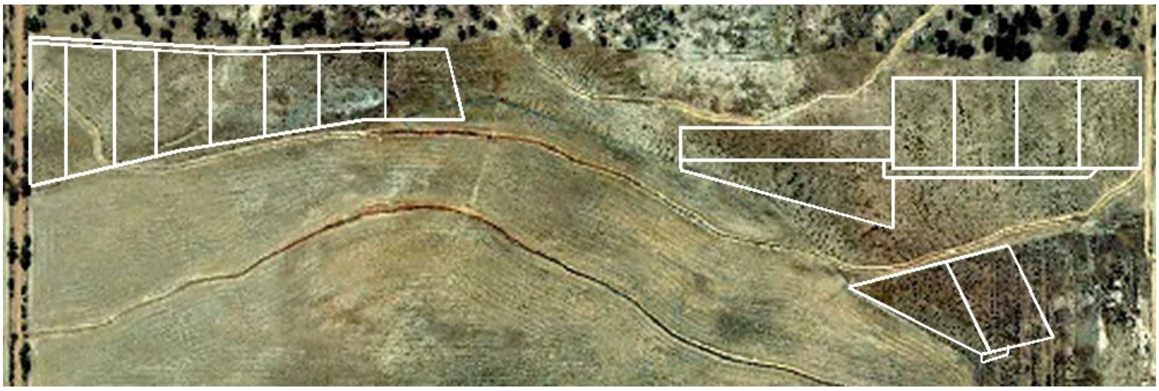
Animals grazing saltbush forage alone are therefore unlikely to maintain weight due to low energy, high soluble salt restricting intake and the presence of anti-nutritional compounds. In many saltland pastures, growth of a low-salt accumulating understorey species may provide a supplement to animals grazing saltbush, however, in highly saline soils or during drought, such understorey may be absent. The second aim of this project was to investigate supplementation strategies for sheep grazing saltbush monocultures. The second hypothesis tested is that feeding supplements with saltbush will reduce weight loss and increase wool growth.

The most common types of supplements that are given to animals during the summer/autumn feed gap in south-western Australia include cereal grains, lupins and cereal hay. Typically, these types of high energy feeds are required to complement low energy, low protein and high fibre senesced annual pastures and crop stubbles. While saltbush is high in salt it has low indigestible fibre (ADF) and high crude protein. It is therefore likely that straws and crop stubbles will complement a saltbush-based diet. The benefits of providing low energy/high fibre straw supplements to sheep eating saltbush have been demonstrated in several pen feeding trials (Warren *et al*. 1990, Roberts 2001). The third hypothesis tested in this study was that there will be no differences in liveweight or wool growth in response to supplementation with grain or roughage when the supplement is provided at equivalent metabolisable energy levels.

Materials and Methods

Experimental site

The experiment was conducted in Yealering, 250 km south-east of Perth (32.60^{o} S, 117.62^{o} E) in Western Australia. The site is adjacent to a riverbed, with gravelly sandy loam soils with an average surface salinity (top 50 cm) of approximately 3.2 dS/m ECe (marginal salinity). The site was selected because it had a dense stand of saltbushes (~ 900 stems/ha) and very little annual understorey growth, partly attributable to the shallow water table. Sixteen 0.75 ha plots of 11 year old saltbush (8 plots of old man and 8 plots of river) were fenced in March 2003. Plots were grazed in autumn/early winter in 2003, 2004 and 2005.



Aerial photo of the research site and layout of the plots, the 8 old man saltbush plots are on the left.

Animal performance

Grazing with weaner Merino sheep (13 sheep/ha in 2003, 8 sheep/ha in 2004 and 2005) commenced in autumn of each year. In 2003 and 2004 all animals were wethers and in 2005 mixed wethers and ewes grazed the plots with an equal distribution of sexes in each plot. Liveweight and condition score (Suiter 1994) were monitored every 7-14 days for the duration of grazing. Animals were not fasted before weighing (either before or during the trial) and were weighed within 1 hour of removal from their plot. Each year, sheep were removed from the plots on the same day and this occurred when the majority of saltbushes had been defoliated to less than 60g of edible dry matter per shrub (50-73 days) and/or when sheep were losing significant weight. Wool growth per day of all sheep was estimated using the dyeband technique described by Landlands and Wheeler (1968). Before introduction to the plots all animals were given an anthelmintic drench, selenium slow release bullet and were vaccinated with Glanvac^{TM} 6 (CSL Ltd Victoria) according to the manufacturer's recommendations.

For each saltbush species, sheep in 2 or 4 of the 8 plots did not receive any supplement, sheep in the remaining plots were offered a supplement of either cereal straw (2 or 3 plots < 350 g/head.day) or barley grain (3 plots - 175 g/head.day), fed 3 times per week. In 2003 barley straw was offered and in 2004 the straw offered was wheaten straw. The supplements were offered at approximately a third of the maintenance requirement for the class and mean weight of the sheep. In 2005, the straw treatment was replaced by oaten hay, offered to animals at a third of their maintenance requirement (330 g/head.day). Grain was fed in a trough and the roughage supplement was presented in a feeder with a roof to keep the feed dry. The type of supplement was allocated to plots each year on a random basis. Sheep had access to unlimited fresh drinking water at all times during grazing. Table 1 describes the time of grazing and supplements allocated to plots each year for the three years of grazing.

Table 1: Annual grazing times and number of supplementation treatments allocated to plots within old man and river saltbush.

Year	Sex[1]	sheep/ha	Date sheep on plots	Date sheep off plots	Duration (days)	Grazing days/ha	Supplementation treatments (number of plots for each of the 2 saltbush species)			
							none	Barley grain	Cereal straw	Oaten hay
2003	w	13	16/03/2003	5/05/2003	50	650	4	2	2	0
2004	w	8	28/04/2004	29/06/2004	62	496	2	3	3	0
2005	w/e	8	1/04/2005	13/06/2005	73	584	2	3	0	3

[1] w = wether and e = ewe

Plant composition, biomass and nutritive value

Plant composition, soil cover and biomass were determined in spring each year (peak biomass) as well as immediately prior to and after grazing. Understorey biomass, vegetation cover and botanical composition were assessed using calibrated quadrate cuts and the dry-weight-rank method of Mannetje and Haydock (1963).

The nutritive value of plant species that provided more than 5% of total biomass and all supplements was estimated using plant samples collected in spring and immediately prior to grazing each year. For the saltbushes, only leaves and small stems (>3mm) were sampled for nutritive value. Representative samples of each plant species were collected along transects within plots, bulked and dried in an oven at 65°C for 48 h. After drying, samples were ground to pass through a 1mm screen using a Tecator Cyclone© mill. Unless indicated, all samples analyses performed in duplicate.

Organic matter, total and soluble ash was determined on plant samples as described by Faichney and White (1983).

In vitro dry matter digestibility was estimated using the pepsin-cellulase digestion method described by (Klein and Baker 1993), calibrated with a range of standards with known *in vivo* digestibility. Pepsin-cellulase digestion of the organic matter in the dry matter (P-CDOMD) (an estimation of the digestibility of the whole sample) was calculated as follows:

$$\text{P-CDOMD} = \frac{\text{organic matter in the sample} - \text{estimate of organic matter in the residue}}{\text{sample dry matter}}$$

For the calculation; estimated organic matter in the residue = residual dry matter (remaining after digestion) – insoluble ash in the residual dry matter.

Residue organic matter could not be directly measured by ashing due to the bags containing the digested samples bursting and spilling during ashing. The calculation used assumed all soluble ash (calculated from an undigested sample) was dissolved during pepsin-cellulase digestion.

Neutral detergent fibre (NDF) was measured using an Ankom 200/220 Fibre analyser in accordance with the operating instructions for this equipment. Sub samples of the dried and ground material were digested for 60 minutes, using a neutral detergent solution, in an ANKOM200/220 Fibre Analyser (Ankom ® Tech. Co., Fairport, NY, USA). This was used to dissolve the easily digested pectins and plant cell components (proteins, sugars and lipids), leaving the fibrous residue (cellulose, hemicellulose and lignin). Acid detergent fibre (ADF) was measured using an Ankom 200/220 Fibre analyser in accordance with the operating instructions for this equipment (Ankom ® Tech. Co., Fairport, NY, USA). ADF was determined sequentially on the samples previously used for NDF. The samples were digested in an acidified quaternary detergent solution to dissolve remaining soluble cell components, hemicellulose and soluble minerals. Again digestion occurred in an ANKOM 200/220 Fiber Analyzer over 60 minutes.

Mineral analyses were conducted by a commercial laboratory (Wesfarmers CSBP Limited). Only one sample of each plant species in spring and autumn were analysed. Total N was determined by combustion using a Leco FP-428 N Analyser (Sweeney and Rexroad 1987). Phosphorous (P), potassium (K), sulphur (S), sodium (Na), calcium (Ca), magnesium (Mg), copper (Cu), zinc (Zn), manganese (Mn), iron (Fe) and boron (B) were measured by ICP-AES (McQuaker et al. 1979). Chloride (Cl) and nitrate were measured using a Lachat Flow Injection Analyser by the method of Zall *et al.* (1959).

Saltbush edible dry matter was predicted using the ‘Adelaide’ technique of Andrew *et al.* (1979). This is a non-destructive comparative ranking technique where a branch representing approximately 20% of a typical shrub is compared to other shrubs along a ‘w-shaped’ transect within each plot. The representative branch is then striped of all leaves and small stems (<3mm) and the material is dried at 65^{o}C for 48 hours. The shrub rankings within plots are then multiplied by the dry material and saltbush numbers to estimate saltbush ‘edible dry matter’ (EDM). Saltbush numbers in each plot were counted at the start of the experiment and again at the end. Mortality rate of saltbushes during the experiment was less than 1%.

Statistical analysis
Liveweight, condition and wool growth data for the mean of plots were compared using ANOVA where the treatment model was saltbush species by supplement (none, barley grain or straw/hay). Saltbush feed on offer prior to grazing, understorey feed on offer prior to grazing and total pasture consumed were all tested as covariates in the ANOVA analyses and removed in all cases as they were not significant.

Results

Initial liveweight, initial condition score, change in liveweight and condition during grazing and clean wool growth per day are presented in Table 2. The significance of differences associated with species of saltbush, supplements and the interactions between species and supplements are presented in Table 3.

2003 Animal production
In total, the plots maintained sheep for 650 grazing days per hectare of saltbush. Sheep grazing old man saltbush gained significantly more weight than those grazing river saltbush after 50 days ($p < 0.01$), these differences were apparent by day 29 of grazing ($p < 0.05$) (Tables 2 and 3). Sheep grazing old man saltbush gained an average of 1.6 kg over 50 days (33 g/head.day) while sheep grazing river saltbush lost an average of 0.2 kg (-4 g/head.day). Addition or type of supplement did not result in a significant difference in liveweight. Changes in condition score were not significantly associated with saltbush species or addition/type of supplement. There were no differences in wool growth associated with either supplement or saltbush species. Sheep grew an average of 10.1 ± 0.33 g of clean wool per head per day when on the plots. At shearing, the wool had a mean fibre diameter of 20.6 ± 0.11 micron and very low staple strength (16 ± 0.5 N/Ktex).

2004 Animal production
In 2004, the sheep at the start of the experiment were heavier (12.7 kg heavier) and had higher condition scores than the experimental sheep from 2003 (Table 2). During grazing in 2004, sheep in all plots lost weight and condition. Sheep remained on the plots for 62 days (496 grazing days per ha). The 2004 data support the 2003 observations in that the sheep grazing old man saltbush lost significantly less weight (-5.6 kg or -90 g/head.day) than those grazing river saltbush (-7.3 kg or -117 g/head.day; $p < 0.01$) however the difference was only significant at the end of the grazing period after 62 days (Table 3). Additionally the sheep grazing old man saltbush lost significantly less condition than the sheep grazing river saltbush ($p < 0.05$, day 62 of grazing). In contrast to observations from 2003, the sheep that grazed the plots in 2004 demonstrated a significant difference in liveweight associated with the addition of supplements ($p < 0.01$). Sheep offered a grain supplement lost less weight than those without supplements (Table 2). The animals fed a straw supplement lost more weight than those that did not receive a supplement. Over the 62 days of grazing the sheep in the old man saltbush plots grew more wool ($p < 0.01$) than the sheep in the river saltbush plots and there was a trend ($p < 0.1$) towards greater wool growth in response to supplements. Clean wool growth per animal in 2004 was half the growth in 2003 (mean 4.8 ± 0.16 g clean wool growth/day). At shearing,

fibre diameter of the flock averaged 18.8 ± 0.15 micron and staple strength averaged 36 ± 1.0 N/Ktex.

2005 Animal production
The sheep were on the plots for a total of 73 days (584 grazing days per ha). In contrast to the previous two years, there was significant rainfall during the grazing period (Table 4), some flooding and understorey plant growth. It was well into winter when the animals were removed from the plots and some plots were not grazed evenly due to some inundation. There were no significant differences between ewes and wethers.

Over the 73 days of grazing sheep maintained liveweight (mean change of 2 g/head.day) and lost 0.2 ± 0.05 condition score units (Table 2). In contrast to the previous two years, no significant differences in liveweight change or condition during grazing were associated with the species of saltbush. There were some differences in liveweight and condition associated with type of supplement, although there differences were only significant on day 41 of grazing ($p < 0.05$ for liveweight and $p < 0.01$ for condition score) and day 73 of grazing ($p < 0.05$ for condition score only). As in 2004, the barley grain supplement was better for animal production than a roughage supplement of the same energy value. The change from barley straw (offered in 2003 and 2004) to oaten hay of higher nutritive value did not result in comparatively better animal performance from roughage. Again, the animals that were not offered a supplement were heavier than those with a roughage supplement. As in 2003, both saltbush species and supplement had no significant impact on wool growth. Sheep grew more wool in 2005, averaging 16 ± 0.7 g clean wool/head.day. At shearing the wool had a fibre diameter of 21 ± 0.2 micron and a staple strength of 37 ± 1.4 N/Ktex.

Table 2: Mean initial liveweight, initial condition, liveweight change during grazing, condition change during grazing and daily clean wool growth during grazing of weaner Merino sheep on saltbush plots, with or without supplements in autumn/winter 2003, 2004 and 2005.

Saltbush species	Supplement	Initial liveweight (kg) ± s.e.	Initial condition score ± s.e.	Weight change (kg) ± s.e.	Condition change ± s.e.	Clean wool growth (g/head.day)
2003, 50 days of grazing						
Old man	Barley grain	38.8 ± 1.13	1.8 ± 0.11	2.4 ± 0.08	-0.3 ± 0.14	11.1 ± 0.99
	Barley straw	39.9 ± 0.41	1.9 ± 0.23	1.6 ± 0.86	-0.4 ± 0.41	10.6 ± 1.12
	No supplement	40.1 ± 0.80	1.8 ± 0.12	0.9 ± 0.77	-0.4 ± 0.08	10.0 ± 0.41
River	Barley grain	40.5 ± 0.27	1.6 ± 0.13	-0.6 ± 0.44	-0.1 ± 0.02	10.2 ± 1.46
	Barley straw	39.2 ± 0.22	1.8 ± 0.03	-0.6 ± 0.65	-0.5 ± 0.06	8.8 ± 0.19
	No supplement	38.6 ± 0.24	1.8 ± 0.06	0.6 ± 0.26	-0.3 ± 0.06	9.9 ± 0.03
Mean of all plots		39.5 ± 0.28	1.8 ± 0.04	0.7 ± 0.33	-0.3 ± 0.05	10.1 ± 0.33
2004, 62 days of grazing						
Old man	Barley grain	52.3 ± 0.14	2.2 ± 0.03	-4.4 ± 0.65	-0.9 ± 0.05	5.3 ± 0.30
	Wheaten straw	52.2 ± 0.04	2.2 ± 0.07	-6.4 ± 0.57	-1.0 ± 0.10	4.9 ± 0.13
	No supplement	52.2 ± 0.25	2.2 ± 0.00	-6.0 ± 1.30	-0.9 ± 0.06	5.1 ± 0.15
River	Barley grain	52.0 ± 0.22	2.1 ± 0.03	-5.8 ± 0.63	-0.9 ± 0.04	4.5 ± 0.35
	Wheaten straw	52.1 ± 0.05	2.2 ± 0.00	-8.3 ± 0.24	-1.0 ± 0.04	3.8 ± 0.28
	No supplement	52.1 ± 0.07	2.2 ± 0.00	-7.7 ± 0.07	-1.1 ± 0.00	4.4 ± 0.19
Mean of all plots		52.2 ± 0.08	2.2 ± 0.01	-6.4 ± 0.40	-1.0 ± 0.03	4.8 ± 0.16
2005, 73 days of grazing						
Old man	Barley grain	46.9 ± 0.76	1.5 ± 0.01	1.1 ± 1.03	-0.2 ± 0.04	17.6 ± 0.60
	Oaten hay	47.3 ± 0.57	1.5 ± 0.08	-1.8 ± 0.29	-0.4 ± 0.06	15.5 ± 1.62
	No supplement	48.1 ± 0.45	1.5 ± 0.04	-0.7 ± 0.92	-0.3 ± 0.08	15.1 ± 0.71
River	Barley grain	47.7 ± 0.71	1.5 ± 0.03	0.4 ± 0.86	-0.1 ± 0.06	16.4 ± 0.48
	Oaten hay	47.3 ± 0.04	1.4 ± 0.04	-1.3 ± 0.54	-0.3 ± 0.03	13.5 ± 1.88
	No supplement	47.3 ± 0.02	1.5 ± 0.10	-0.5 ± 0.15	-0.3 ± 0.17	18.1 ± 3.80
Mean of all plots		47.4 ± 0.21	1.5 ± 0.02	-0.5 ± 0.36	-0.3 ± 0.03	16.0 ± 0.67

Table 3: Significance of differences in mean initial liveweight, initial condition, liveweight change during grazing, condition change during grazing and daily clean wool growth of weaner Merino sheep on saltbush plots, with or without supplements in autumn/winter 2003, 2004 and 2005.

		Source of variation		
Year	Measurement	Saltbush species	Supplement	Interaction
2003	Initial liveweight	ns[1]	ns	ns
	Liveweight on day 14	ns	ns	ns
	Liveweight on day 29	*	ns	ns
	Liveweight on day 43	^	ns	ns
	Liveweight on day 50	**	ns	ns
	Initial condition score	ns	ns	ns
	Condition score on day 50	ns	ns	ns
	Clean daily wool growth	ns	ns	ns
2004	Initial liveweight	ns	ns	ns
	Liveweight on day 20	ns	ns	ns
	Liveweight on day 35	ns	ns	ns
	Liveweight on day 49	ns	^	ns
	Liveweight on day 62	**	**	ns
	Initial condition	ns	ns	ns
	Condition score on day 20	ns	ns	ns
	Condition score on day 35	ns	ns	ns
	Condition score on day 49	ns	ns	ns
	Condition score on day 62	*	^	ns
	Clean daily wool growth	**	^	ns
2005	Initial liveweight	ns	ns	ns
	Liveweight on day 27	ns	ns	ns
	Liveweight on day 41	^	*	ns
	Liveweight on day 54	ns	^	ns
	Liveweight on day 61	ns	ns	ns
	Liveweight on day 73	ns	^	ns
	Initial condition score	ns	ns	ns
	Condition score on day 27	ns	ns	ns
	Condition score on day 41	ns	**	*
	Condition score on day 54	ns	ns	ns
	Condition score on day 61	^	ns	ns
	Condition score on day 73	ns	*	ns
	Clean daily wool growth	ns	ns	ns

[1]Significance of differences: *** $p \leq 0.001$, ** $p \leq 0.01$, * $P \leq 0.05$, ^ $p \leq 0.1$ and ns is not significant

Saltbush and Understorey Biomass

At the start of the experiment, the old man saltbush plots contained 931 ± 33 shrubs/ha and the river saltbush plots had 866 ±77 shrubs/ha. Saltbush biomass each autumn, prior to grazing, ranged from approximately 400 to 700 kg of ‘edible’ (leaves and stems < 3mm) dry matter per ha. In 2003, there was significantly more ($p < 0.05$) old man saltbush when grazing commenced (Table 4). In contrast, there was significantly more river saltbush in autumn 2004 and 2005 ($p < 0.05$). Across species, saltbushes rarely grew more than 700g of edible dry matter per shrub per year (Figure 1). The volunteer understorey produced approximately 1.7 t DM/ha (spring 2003 and 2005). Biomass in autumn, prior to grazing, did not exceed 500 kg of DM/ha (Table 4). In total the plots provided approximately 1 t DM/ha each autumn.

Twenty-two plant species that were regularly identified in the plots (Table 5). The species that provided the most biomass during autumn included the saltbush species (48 to 72 % of total 'edible' biomass in autumn) and grasses. Botanical composition of the understorey in autumn was dominated by coast barbgrass (*Parapholis incurva*, 21 to 45% of understorey biomass), annual ryegrass (*Lolium rigidum,* 11 to 20 % of understorey biomass), barley grass (*Hordium leporinum*, 11 to 20 % of understorey biomass), stonecrop (*Crassula* spp., 11 to 22 % of understorey biomass), prostrate lovegrass (*Erogostis dielsii*, 1 to 7 % of understorey biomass) and plantain (*Plantago coronopus*, 1 to 6 % of understorey biomass). Additional species that contributed more than 5% to understorey composition in the spring included waterbuttons (*Cotula coronopifolia* – up to 30% of spring biomass but less than 1% of autumn biomass), capeweed (*Arctotheca calendula*), red brome grass (*Bromus rubens*), sorrel (*Rumex bucephalophorus*) and woolly clover (*Trifolium tomentosum*). The legume component of the understorey provided less than 220 kg/ha in spring. Of the 22 plant species commonly identified in the plots, 4 were perennial; old man saltbush, river saltbush, puccinellia (*Puccinellia ciliata*) and prostrate lovegrass. Three species were native to Australia; old man saltbush, river saltbush and prostrate lovegrass.

Table 4. Mean plant dry matter (kg/ha) during the experimental period 2003 to 2005

		Total 'edible' biomass		Understorey biomass		[1]Sign. off diff.	Saltbush 'edible'		Sign. of diff.	
Date	Time	Old man plots	River plots	Old man plots	River plots	species	Old man plots	River plots	species	Covariate (shrub number)
17/04/03	Sheep on	1128	870	486 ± 22.0	366 ± 35.8	*	642 ± 33.0	504 ± 46.8	*	*
2/07/03	Sheep off						7 ± 0.4	18 ± 1.5	***	^
2/10/03	Spring	1678	1545	1601 ± 111.2	1327 ± 47.3	*	77 ± 9.1	218 ± 14.7	***	**
20/04/04	Sheep on	827	1057	434 ± 44.6	540 ± 60.8	^	393 ± 32.3	517 ± 15.8	**	ns
30/06/04	Sheep off	413	268	317 ± 55.1	178 ± 55.4	ns	96 ± 7.4	90 ± 5.7	ns	ns
2/10/04	Spring	496	783	445 ± 59.7	305 ± 48.9	^	491 ± 22.2	487 ± 27.0	ns	ns
22/03/05	Sheep on	1076	977	465 ± 47.5	269 ± 58.6	*	611 ± 14.2	708 ± 45.4	*	^
14/06/05	Sheep off	415	197	223± 23.6	145 ± 34.4	^	192 ± 23.0	52 ± 8.7	***	ns
11/10/05	Spring	1890	1528	1461 ± 96.4	1241 ± 178.5	ns	429 ± 52.8	287 ± 35.1	^	*

[1]Significance of differences: *** p≤0.001, ** p≤0.01, * P≤0.05, ^ p≤ 0.1 and ns is not significant

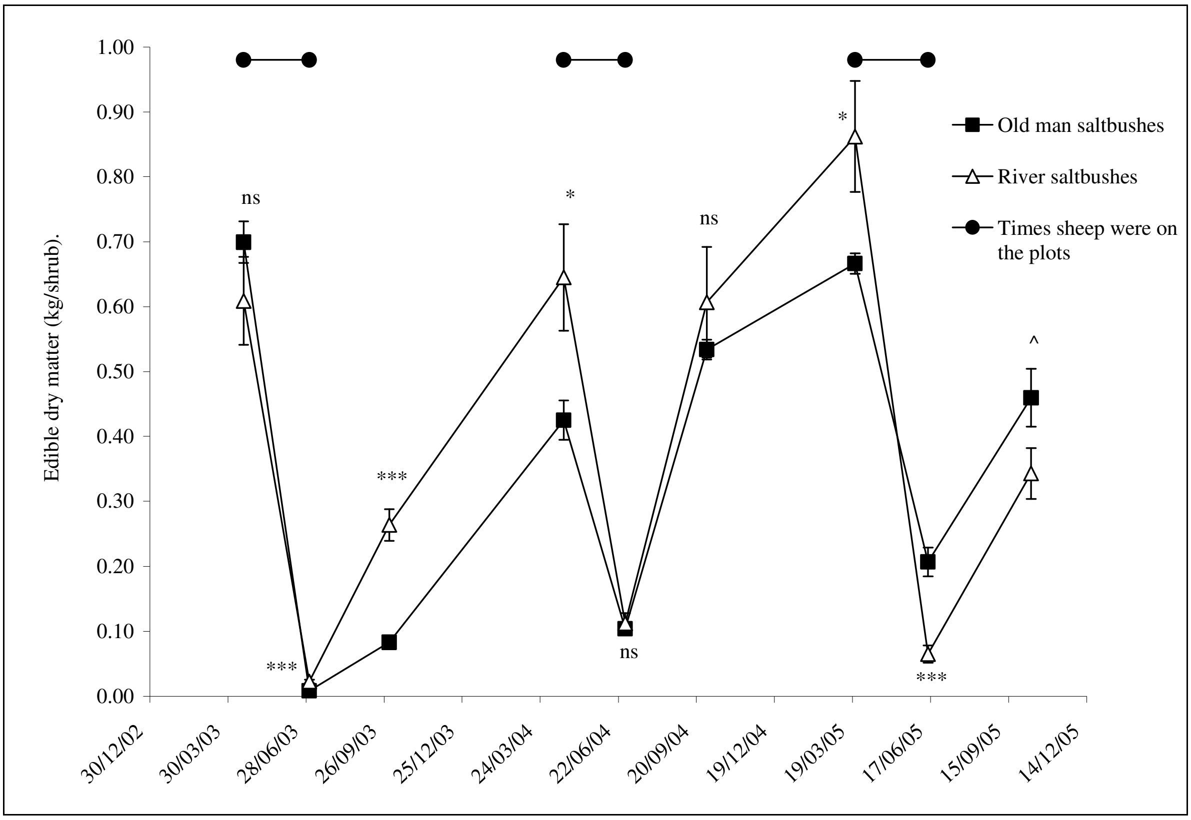


Figure 1. Mean edible dry matter per shrub for old man and river saltbushes growing on saline land and grazed each autumn. [1]Significance of differences: *** p ≤ 0.001, ** p ≤ 0.01, * p ≤ 0.05, ^ p ≤ 0.1 and ns is not significant

Nutritive value of biomass

The *in vitro* nutritive values of individual plant species, sampled in spring and autumn, are presented in Table 6. Both old man and river saltbushes have energy levels that are below the maintenance requirement for weaner wethers (DOMD of 52 and 48 % respectively). Crude protein was higher in old man saltbush (13.6%) than river saltbush (11.3%). The saltbushes also accumulate high levels of ash (26 % for old man saltbush and 21 % for river saltbush) and for both species 4% of total DM is insoluble ash. The saltbushes therefore have 17 to 22% soluble salt in the DM and this was mostly chloride (7.3 to 7.9 %), sodium (5.2 to 5.8%) and potassium (1.2 to 2.4%). The soluble salts in old man saltbush consisted of a higher portion of potassium chloride than for river saltbush. The saltbushes both had high sulphur in the DM (0.38% for old man saltbush and 0.49 % for river saltbush). There was little variation in the nutritive value of saltbush between seasons or years (data not presented).

Table 5. Mean botanical composition (% of DM) of understorey biomass in the old man and river saltbush plots in spring and prior to grazing in autumn.

Common name	Scientific name	Spring 2003		Spring 2004		Spring 2005		Autumn 2004		Autumn 2005	
		Old man plots	River plots	Old man plots	River plots	Old man plots	River plots	Old man plots	River plots	Old man plots	River plots
Coast barbgrass	*Parapholis incurva*	17 ± 2	24 ± 4.4	20 ± 3.4	37 ± 8.3	32 ± 3	31 ± 5	30 ± 5.1	37 ± 7.9	21 ± 3.6	45 ± 6.8
Annual ryegrass	*Lolium rigidum*	7 ± 2.2	7 ± 1.9	12 ± 2.2	7 ± 4.5	7 ± 1.6	9 ± 3.3	20 ± 5.3	13 ± 5.8	11 ± 4.3	15 ± 5.2
Barley grass	*Hordium leporinum*	2 ± 1.3	2 ± 1.3	6 ± 2.6	7 ± 3.9	5 ± 1.5	5 ± 3	13 ± 5.5	11 ± 3.7	20 ± 6.1	14 ± 5.2
Brome grass	*Bromus rubens*	1 ± 0.5	1 ± 0.6	6 ± 1.5	1 ± 1.3	4 ± 1.3	1 ± 0.7	0 ± 0.1	0 ± 0	5 ± 1.1	2 ± 1.2
Silvergrass	*Vulpia myuros*	1 ± 0.3	1 ± 0.4	0 ± 0	0 ± 0	3 ± 1.5	1 ± 0.7	3 ± 2.1	3 ± 1.1	0 ± 0	0 ± 0
Puccinellia	*Puccinellia ciliata*	4 ± 2.8	4 ± 2.2	0 ± 0	0 ± 0	4 ± 1.9	3 ± 2.6	3 ± 1.5	2 ± 1.5	1 ± 1.4	2 ± 1
Prostrate lovegrass	*Erogostis dielsii*	0 ± 0	1 ± 0.7	3 ± 1.3	1 ± 1	0 ± 0	2 ± 0.7	1 ± 0.4	5 ± 1.3	7 ± 4.2	1 ± 0.6
Waterbuttons	*Cotula coronopifolia*	24 ± 2.8	8 ± 1.8	30 ± 4.4	11 ± 3.4	20 ± 1.9	17 ± 2.1	0 ± 0	0 ± 0	1 ± 0.4	1 ± 0.5
Salt sand spurrry	*Spergularia marina*	0 ± 0	0 ± 0	0 ± 0	0 ± 0.2	0 ± 0	0 ± 0	0 ± 0.2	0 ± 0.1	0 ± 0	2 ± 0.9
Stonecrop	*Crassula spp.*	16 ± 5.3	11 ± 4.7	8 ± 2.5	10 ± 3.7	8 ± 2.7	13 ± 3.7	17 ± 2.6	11 ± 3.9	22 ± 6	12 ± 4.1
Capeweed	*Arctotheca calendula*	8 ± 3.1	6 ± 2.9	4 ± 2.8	4 ± 1.9	2 ± 1	5 ± 2.3	5 ± 2.1	3 ± 1.1	5 ± 4.4	1 ± 0.4
Thread iris	*Gynandriris setifolia*	0 ± 0	1 ± 0.5	0 ± 0.1	1 ± 0.6	0 ± 0.4	2 ± 1.1	0 ± 0	0 ± 0	0 ± 0	1 ± 0.5
Sorel	*Rumex bucephalophorus*	2 ± 0.8	10 ± 2.7	0 ± 0.5	7 ± 2.6	0 ± 0.5	1 ± 0.3	0 ± 0.1	2 ± 0.6	0 ± 0	0 ± 0.1
Plantain	*Plantago coronopus*	3 ± 0.7	7 ± 2	0 ± 0.2	6 ± 2.5	1 ± 0.6	4 ± 1.4	1 ± 0.9	6 ± 1.7	1 ± 0.7	5 ± 2.3
Flat weed	*Hypochaeris radicata*	0 ± 0.3	1 ± 0.5	0 ± 0	0 ± 0	0 ± 0.5	0 ± 0.4	0 ± 0	0 ± 0.1	0 ± 0	0 ± 0
Iceplant	*Mesembryanthemum nodiflorum*	1 ± 0.4	0 ± 0	1 ± 0.6	1 ± 0.7	0 ± 0	0 ± 0.2	0 ± 0	0 ± 0	0 ± 0.1	0 ± 0.1
Subterranean clover	*Trifolium subterraneum*	3 ± 2.1	3 ± 2	1 ± 0.7	0 ± 0.1	3 ± 1.7	1 ± 0.5	0 ± 0.1	0 ± 0	1 ± 0.8	1 ± 0.5
Cluster clover	*Trifolium glomeratum*	1 ± 0.8	3 ± 1.8	0 ± 0.1	1 ± 0.7	3 ± 1.3	1 ± 1.2	2 ± 1	3 ± 2.6	1 ± 0.7	0 ± 0.1
Woolly clover	*Trifolium tomentosum*	8 ± 1.6	7 ± 2.3	8 ± 2.9	5 ± 2.1	8 ± 1	4 ± 2.6	4 ± 1.9	3 ± 1.8	2 ± 1.3	0 ± 0
Haresfoot clover	*Trifolium arvense*	0 ± 0.5	2 ± 1.4	0 ± 0.2	1 ± 0.6	0 ± 0.1	0 ± 0.4	0 ± 0	1 ± 0.5	0 ± 0	0 ± 0

The wheaten straw (fed in 2003) and barley straw (fed 2004) was chosen to represent typical cereal crop residues that may be adjacent to saline areas. Both had low energy values (DOMD of 46%) and high acid detergent fibre (46 to 50%). They differed in that the wheaten straw had higher crude protein than the barley straw (9.7 compared to 4.7%) and the wheaten straw contained higher ash than the barley straw (24 compared to 8%). The high ash in the wheaten straw was largely insoluble. In comparison, the roughage offered in 2005, oaten hay, had much higher *in vivo* nutritive value with a DOMD of 55%, ADF of 32%, crude protein of 6.9% and 5% ash. The barley grain supplements offered each year had similar *in vivo* nutritive values with a mean DOMD of 74%, 9.7% crude protein and 6% total ash.

In autumn, the understorey plants with the highest DOMD (all over 54%) included; puccinellia (green), prostrate lovegreass (green), waterbuttons (green), coast barbgrass (senesced), barley grass (senesced) and brome grass (senesced). The plants with the lowest energy values (below 50%) included; plantain, stonecrop woolly clover and sorrel (all senesced at the time of sampling). The understorey plants that contained more than 11% crude protein in autumn included; puccinellia, woolly clover, cluster clover and sorrel. Several understorey species accumulated excessive ash. Coast barbgrass, silver grass, woolly clover and cluster clover all had up to 20% ash, the majority of which was insoluble. Capeweed and stonecrop both contained 32% ash in the DM, 6 to 10% of the dry matter was soluble ash. The single sample of plantain collected in autumn contained 42% ash, most of which was insoluble. Stonecrop contained 0.49% sulfer in the DM, the same amount as river saltbush.

The majority of understorey plants had higher energy and protein levels in spring than autumn. Plants with DOMD higher than 60% included capeweed, stonecrop, puccinellia, annual ryegrass, wooly clover, cluster clover (*Trifolium glomeratum*), subterranean clover (*Trifolium subterraneum*) and barley grass. With the exception of plantain (21 % ash), all species had ash levels in the DM below 15%. Legumes had higher crude protein than grasses and forbes.

Table 6. *In vitro* nutritive value and mineral composition of saltbushes, supplements and understorey species (collected in autumn and spring each year).

Sample	DOMD (%)		M/D		Total ash (%)		Insoluble Ash (%)		NDF (%)		ADF (%)		CP (%)		P (%)	K (%)	S (%)	Na (%)	Ca (%)	Mg (%)	Cl (%)	Cu mg/kg	Zn mg/kg	Mn mg/kg	Fe mg/kg
	mean[1]	se[1]	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se											
Old man saltbush[2]	52	1.4	7.6	0.25	26	1.8	4	0.2	28	0.6	17	0.6	13.6	0.85	0.21	2.41	0.38	5.25	0.70	0.67	7.33	4.1	40	293	88
River saltbush[2]	48	4.2	6.8	0.76	21	2.3	4	0.2	41	3.2	28	3.1	11.3	1.26	0.31	1.21	0.49	5.78	0.77	1.24	7.95	3.3	42	261	67
Supplements																									
Barley grain	74	3.7	11.6	0.66	6	3.6	1	0.2	22	0.8	5	0.4	7.9	2.30	0.41	0.55	0.13	0.04	0.06	0.11	0.12	5.9	24	18	93
Wheaten straw	46		6.5		24		21		54		46		9.7												
Barley stubble	46		6.6		8		7		76		50		4.7		0.08	0.19	0.06	0.06	0.19	0.06	0.06	4.2	15	71	767
Oaten hay	55		8.2		5		1		62		32		6.9		0.14	0.98	0.10	0.70	0.17	0.15	1.18	2.8	9	28	93
Understorey plants in autumn																									
Coast barbgrass	55	2.2	8.1	0.40	20	6.5	18	5.9	63	6.3	43	5.9	4.6	0.27	0.10	0.11	0.08	0.17	0.31	0.11	0.18	4.8	23	47	622
Annual ryegrass	50	2.4	7.2	0.43	8	3.0	6	1.3	68	1.6	40	2.2	6.2	2.62	0.08	0.15	0.06	0.14	0.18	0.07	0.19	2.3	13	56	204
Barley grass	54	1.8	8.0	0.32	13	3.1	10	0.9	63	5.4	41	0.2	4.8	0.95	0.09	0.17	0.09	0.48	0.51	0.43	0.31	4.3	23	70	1148
Brome grass	54		8.0		9		9		73		49		3.9		0.06	0.08	0.05	0.04	0.22	0.06	0.08	4.1	10	64	842
Silver grass	51	5.1	7.4	0.92	18	13.5	17	12.7	70	3.3	50	0.4	7.7	4.70											
Puccinellia	57	2.7	8.5	0.48	14	3.7	10	2.2	59	5.9	36	3.7	12.6	5.59											
Prostrate lovegrass	57		8.5		5		3		68		38		3.3		0.06	0.29	0.07	0.30	0.16	0.07	0.46	3.6	10	40	387
Waterbuttons	56		8.4		6		5		70		35		5.1		0.07	0.38	0.12	0.33	0.17	0.11	0.64	3.3	10	60	584
Stonecrop	44	4.9	6.1	0.87	32	5.8	22	10.8	51	7.1	36	7.3	7.2	2.08	0.21	1.35	0.49	6.15	0.47	0.64	8.41	3.2	16	127	132
Capeweed	51	5.4	7.4	0.98	32	7.4	26	8.0	53	8.6	43	7.5	12.8	3.89	0.14	0.31	0.10	0.40	1.46	0.42	0.19	9.6	36	108	1553
Sorell	47		6.6		7		6		70		46		4.8		0.16	0.31	0.08	0.17	0.32	0.23	0.22	4.7	21	34	381
Plantain	42		5.7		42		36		66		51		12.2												
Cluster clover	48	5.2	6.8	0.94	21	4.8	17	2.7	62	2.8	45	1.9	11.8	1.02	0.17	0.26	0.12	0.18	0.91	0.17	0.24	7.1	32	53	786
Woolly clover	47		6.7		20		16		62		47		12.1		0.15	0.22	0.11	0.12	0.84	0.17	0.10	5.8	23	42	874
Understorey plants in spring																									
Coast barbgrass	59	8.6	8.7	1.55	12	4.5	4	1.0	55	6.5	29	5.4	6.8	0.89	0.23	1.54	0.19	0.59	0.31	0.21	1.35	3.7	26	78	241
Annual ryegrass	62	5.1	9.3	0.93	6	0.9	3	0.7	55	4.1	30	3.5	7.1	0.49	0.23	1.29	0.15	0.31	0.23	0.12	0.67	3.1	18	104	148
Barley grass	61	2.1	9.1	0.38	11	2.9	5	1.8	56	4.3	30	1.4	13.5	4.48	0.39	1.98	0.24	0.41	0.28	0.20	1.30	4.5	21	61	303
Brome grass	59	2.6	8.8	0.46	6	1.2	2	0.1	63	0.1	36	0.5	6.6	0.42	0.23	1.14	0.10	0.07	0.18	0.09	0.52	4.9	16	155	127
Puccinellia	67	0.6	10.3	0.10	8	0.7	4	0.8	53	0.8	26	0.9	10.1	1.09	0.26	0.97	0.17	0.35	0.58	0.16	0.67	6.2	17	63	629
Waterbuttons	51	3.5	7.4	0.64	14	1.8	6	0.8	35	5.5	27	4.1	6.9	0.20	0.33	1.18	0.48	1.24	0.85	0.40	1.58	4.4	30	284	719
Stonecrop	70		10.8		9		3		31		20														
Capeweed	72		11.1		10		7		38		30		7.6		0.21	1.34	0.12	1.22	0.90	0.27	1.75	7.0	22	403	511
Sorell	50		7.1		10		10		38		30		11.7												
Plantain	45		6.3		21		5		55		36		7.1												
Subterranean clover	60	7.0	9.0	1.25	14	7.4	13	6.4	47	8.3	33	5.9	17.4	0.92	0.18	1.14	0.15	1.04	0.83	0.25	0.86	5.0	19	122	223
Cluster clover	62	0.2	9.3	0.04	15	4.2	4	0.2	36	4.5	23	5.2	15.6	0.38											
Woolly clover	63	2.3	9.5	0.42	10	0.2	5	1.8	40	4.2	28	3.6	16.4	2.18	0.25	1.21	0.27	1.19	0.95	0.26	1.54	3.8	22	41	230

[1]Mean and standard error of the mean from 6 samples (saltbushes), 3 samples (grain and understorey species). Where there is no standard error, only a single sample was collected and analysed. Mineral analysis was performed on samples collected in a single year (2004).

[2]Limited *in vivo* information suggests that the pepsin-cellulase method overestimates the digestibility of saltbush by up to 10%.

Discussion

Old man saltbush had a higher feeding value than river saltbush

The first hypothesis, that sheep grazing river saltbush will be heavier and grow more wool than those grazing old man saltbush, was not supported by the data. In contrast, during 2 out of 3 years (2003 and 2004), the sheep grazing the old man saltbush plots were heavier at the end of the grazing than sheep from river saltbush plots. Moreover, in 2004, the sheep grazing old man saltbush grew significantly more wool (approximately 18%) than sheep grazing river saltbush. Lack of a difference associated with saltbush species in 2005, is probably associated with unusual seasonal conditions. Considerable out of season rainfall was recorded shortly after animals were introduced to the plots and consequently the annual understorey germinated, providing high energy feed.

It is unlikely that the inferior performance of sheep grazing river saltbush was related to the quantity of saltbush or understorey biomass on offer. In 2004, immediately prior to grazing, the river saltbush plots contained significantly more saltbush biomass and the same understorey biomass as the old man saltbush plots. Understorey biomass and saltbush biomass, prior to grazing, were not significant when tested as covariates within the ANOVA. Differences in performance between sheep grazing the saltbush species are more likely to be associated with differences in the nutritive value of the shrubs or voluntary feed intake. *In vitro* laboratory analyses suggest that the old man saltbush had higher energy levels than river saltbush (DOMD of 52% compared to 48%), less fibre (17% compared to 28% ADF) and higher crude protein (13.6% compared to 11.3%). These differences are consistent with previous observations at another saline site in southern Australia (Norman *et al*. 2004). Using the ruminant nutrition model GrazFeed (Freer *et al.* 1997), an 11 month old weaner wether (liveweight of 47 kg) without supplements and with unlimited biomass on offer, will eat 0.83 kg of old man saltbush DM or 0.72 kg of river saltbush DM. An animal fed old man saltbush is predicted to lose 44 g of liveweight/day and grow 4 g of clean wool per day whereas an animal grazing river saltbush is predicted to lose 88 g of liveweight/day and grow on 3.2 g of clean wool/day. In 2003 and 2005 however the sheep that were not offered a supplement either gained weight or nearly maintained weight. It is likely that animals achieved this through selecting understorey plants with a higher energy value than saltbush; candidate species included coast barbgrass and prostrate lovegrass.

Although old man saltbush had higher energy and crude protein, the biomass contained more salt than river saltbush biomass (26 % versus 21% ash), again supporting previous findings (Norman *et al.* 2004). High concentrations of salt in feed or drinking water depresses food intake (Peirce 1957; Wilson 1966; Masters *et al.* 2005), lowers the efficiency of conversion of digestible energy to metabolisable energy (Arieli *et al*. 1989; Masters *et al.* 2005) and reduces growth (Masters *et al.* 2005). However given better performance of sheep grazing old man saltbush, the 5% difference in ash between old man and river saltbush may not be as much of a limitation as 2 % lower DOMD and 2.3 % lower crude protein. Other differences between the shrubs, including sulphur concentration and architecture, could also be associated with the differences in sheep productivity we observed.

The saltbush in this study had very high sulphur levels and both the saltbush and understorey had low copper. Sulphur is an essential mineral for sheep and deficiency of sulphur in dry pastures in southern Australia can limit liveweight gain and wool growth (White *et al*. 1997). Sheep breeds that are selected for wool growth (such as the Merino) are particularly susceptible to sulphur deficiency (Bird, 1974). Sulphur levels in plant DM typically range from 0.05 to 0.5% and the margin between desirable and harmful concentrations is small (Underwood and Suttle, 1999). Hills *et al.* (1998) found that when given a choice, lambs select a diet with 2 g/day sulphur and Bird (1972) recommended that sulphur in the DM should not exceed 4 g/day. Diets of 0.25 to 0.35 % sulphur in DM are deemed to be high for sheep (Standing Committee on Agriculture, 1990). Sulphur is used primarily in conjunction with N for production of microbial crude protein and a N:S ration of 12.5:1 is considered optimal for sheep (Standing Committee on Agriculture, 1990). If the ratio is too low, excess degradable sulphur is converted to sulphide in the rumen and this can have a number of negative effects on the animal including; reduced intake, growth and motility of the rumen (Bird 1972), damage to the central nervous system (Raisbeck 1982) and induced copper deficiency through reduced copper absorbability (Bird, 1970, Underwood and Suttle, 1999). Copper is an essential mineral, important in the activation of a large number of enzymes. Copper deficiency leads to anemia, bone disorders, connective tissue disorders, neonatal ataxia (swayback), cardio vascular disorders, loss of pigment, diarrhoea and infertility (Underwood and Suttle, 1999). Although it is difficult to predict the exact dietary requirement of copper due to variation in absorption and antagonism from sulphur and other elements, Underwood and Suttle (1999) suggest a diet for lambs should contain > 4 mg Cu/kg DM^{-1} at highest absorbability and as much as 17 Cu/kg DM^{-1} at lowest absorbability.

In this study, river saltbush contained 0.49 % sulphur in the dry matter, higher than the old man saltbush with 0.38 %. The sulphur content was even higher if it is presented as a proportion of total organic matter. The N:S ratio in the saltbushes was considerably higher than the recommended ratio with river saltbush having an N to S ratio of 3.7:1 and old man saltbush having a ratio of 5.7:1. The ratio becomes even less favourable if the high levels of non-protein nitrogen in saltbush are taken into account (Norman *et al.* 2004). Both saltbush species had low copper (old man averaged 4.1 Cu/kg DM^{-1}, river saltbush averaged 3.3 Cu/kg DM^{-1}) as did the straw supplements and the majority of understorey species. This means that saltbush offers positive opportunities in the provision of sulphur to animals during the summer and autumn, however, care must taken to avoid sulphur toxicity and copper deficiency, particularly in young animals. An incidence of neonatal ataxia in Greece has been attributed to ewes grazing sulphur rich halophytic pastures in a costal region (Spais 1959, Underwood and Suttle, 1999). The sulphur and copper status of sheep grazing saltbush-based pastures in Australia should be investigated in future grazing studies.

Compared to herbaceous annual pastures, fodder shrubs have a greater spatial distribution (or lower bulk density) of edible nutrients (Warren and Casson 1993). Both bite weight and bite rate influence voluntary feed intake of ruminants (Ungar and Noy Meir 1998). Shrub architecture may therefore play a significant role in the performance of animals grazing the two saltbush species. Old man saltbushes are erect, conical in shape, can reach 2 m in height and have relatively large leaves (2 to 5 cm in diameter with an oblong to round shape). Many of the leaves are found close together on soft twigs. In comparison, the river saltbushes were prostrate and spreading (plants ranging from approximately 1 to 4 m in diameter with average height of less than 1 m). Leaves of river saltbush are much smaller than those of old man saltbush (0.5 cm wide and 1-2 cm in length) and are spread apart on small woody twigs. Although not tested, it is possible that sheep grazing old man saltbush would be able to get more biomass in each bite. The architecture is such that it is also likely to be easier for the animals to get to the leaves of old man saltbush with less risk of damage to eyes from twiggy branches and without having to climb into the large bushes, thus allowing a raster bite rate.

Provision of supplements improved animal performance in 2 of 3 years

The second hypothesis was that provision of a supplement will improve animal performance. This hypothesis was only partially supported by the data in 2 of the 3 years (2004 and 2005) where animals given a supplement (amounting to one third of their energy requirement for maintenance) were heavier and had higher condition scores. In 2004, there was also a trend ($p \leq 0.1$) for animals that were given supplements to grow more wool. Each year, the value of supplements was not apparent until towards the end of the grazing period (328 grazing days in 2005 and 496 grazing days in 2004). In 2003, we observed no benefits to supplementation when compared across saltbush species. For sheep grazing old man saltbush, animal provided grain were heavier and had lost less condition by the end of the trial, however, in contrast to our expectations, sheep grazing river saltbush without supplements had 200% higher liveweight gain than sheep that were provided with either a grain or straw supplement. An explanation for this anomaly is that the sheep may have been substituting supplement and saltbush rather than eating a combination of both.

Grain supplements improved animal performance, roughage supplements did not.

The third hypothesis tested by this study predicts that there will be no differences in animal performance associated with grain or roughage supplements when the quantity of supplement provided approximates 30% of an animal's daily metabolisable energy requirement. The data does not support this hypothesis and there was only a positive response in terms of liveweight, condition or wool growth to grain supplements. There was little evidence of a positive response to either the straws or hay; the only positive response to straw was recorded in 2003 when sheep grazing old man saltbush with straw were a little heavier and grew 0.6 g of extra clean wool per day than sheep without a supplement. In all other cases the productivity of plots of sheep that were offered a roughage supplement was similar to the productivity of plots of sheep that were not given any supplement.

Overall grain supplementation of 175 g/head.day (roughly one third of the maintenance requirement) led to approximately 5% more wool growth and higher liveweight compared to sheep that were not given a grain supplement. The complementarity between saltbush and grain is attributable to several factors. Firstly there is the direct provision of extra energy that has low fibre and therefore is unlikely to 'compete' with saltbush or understorey for space in the rumen. Gut fill is a major constraint to intake and therefore performance of animals on high fibre roughage diets (Weston 1996). Secondly, provision of soluble carbohydrates improves the conversion of non-protein N to microbial protein in the rumen (Arieli *et al.* 1989). Norman *et al.* (2004) estimated that sheep grazing saltbush could lose up to 8 g of non-protein nitrogen per day unless extra energy was given to animals. If sulphide toxicity is limiting intake or performance, improved utilisation of nitrogen by rumen microbes may also lead to a reduction in sulphide leaving the rumen as more sulphur is incorporated into microbial protein. Finally energy supplements can allow animals to ingest more toxins in the diet and reduce the time taken to adapt to toxins because high-energy substrates are required for detoxification processes (Parkinson 2001, Provenza et al 2003). The benefits of grain supplements to sheep grazing saltbush also have been demonstrated by Hassan and Abdel-Aziz (1979) who found that intake of saltbush by sheep increased significantly when 100 g day of barley was added to the diet and 150 g barley decreased rumen ammonia by 57% and increased N retention.

Complementarity between saltbush and low quality roughage has been demonstrated in several feeding trials with pen-fed animals. Warren *et al.* (1990) found that sheep fed a 1:1 mixture of hay (DMD of 57%) and saltbush, ate 1.5 kg of dry matter per day, significantly higher than the intake of sheep eating hay alone (0.9 kg of dry matter per day) or saltbush alone (0.7 kg of dry matter per day, similar to our prediction of intake for river saltbush in this trial). On the mixed diet, sheep gained 70 g/day but on hay alone or saltbush alone they lost -25 and -225 g/day respectively. Roberts *et al.* (2001) found that penned sheep offered a 3:2 mixture of saltbush and grain-harvester trash (with DMD of 43%) ate 43% more DM than sheep offered saltbush alone and 74% more than sheep offered the grain-harvester trash alone. It has been postulated that the two limitations to intake (salt and fibre) were operating independently of each other (at least partially) so sheep could eat saltbush until they reaches a salt intake limit then eat a large quantity of additional roughage as saltbush is low in fibre (Masters *et al.* 2005). In this study, there were no positive responses in liveweight, condition or wool growth in sheep given a straw or hay roughage compared to animal that were not given a supplement. Animals in the field had a choice between a number of feeds such as saltbush, understorey and the supplements whereas the animals in the pen feeding trials were offered a single prepared diet of either a single feed or a mixed saltbush/roughage ration. In animal house studies therefore the sheep could not separate the saltbush from the poor quality roughage and were forced to consume a pre-determined combination. In this study, we did not observe sheep consuming much of the roughage. So although complementarity between saltbush and poor quality roughage is possible in an animal house where sheep have feed choices, it may not be practical in extensive grazing systems.

Recent work by Thomas *et al.* (2006) examined voluntary diet selection of penned animals offered choices between high salt, high energy diets (offered to every animal) and a range of low salt diets of differing energy and protein levels. They found that sheep offered the high energy, low salt diet ate little of the high salt, high energy diet whereas sheep offered a low energy, low salt diets chose to eat mostly the high salt alternative. They concluded that supplements high in energy are more likely to be consumed by sheep grazing saltbush than roughage supplements. Additionally, they suggested that roughage supplements should have DOMD of between 52 and 60 % for complementarity with the high salt diet, where animal can choose their diet.

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Sheep production, plant biomass and nutritive value of a saltbush-based pasture system subject to rotational grazing or set-stocking for 9 months of the year

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Key outcomes

- Saltbush pastures, consisting of wide spaced rows of saltbush with a sown legume understorey are capable of supporting 7 growing animals per ha for nine months of the year on mildly saline land in the low rainfall wheat belt of Western Australia (330 mm annual rainfall)
- This stocking rate is higher than district average stocking rates for pastures that are not salt-affected (M. Lloyd pers comm.).
- During Autumn and early winter the pasture provides only a maintenance diet however when the understorey components of the system are active and have high nutritive value, animals can grow at a rate of more than 300g per week.
- Over the experiment the sheep produced from 11 to 17.4 kg of clean wool/ha per year with an approximate value of between $88/ha to $129/ha (based on 12 month average prices in 2006).
- While there were some animal production and pasture composition benefits to using rotational grazing, it remains unclear if the extra effort required to manage the animals is justified in the return.
- Before this study little was known about diet selection of sheep grazing saltbush. Using the carbon isotope ratio technique, we found sheep eat more saltbush when the digestibility of the understorey is lowest and animals vary in the amount of saltbush they choose to eat.
- The growth rate of old man saltbush EDM ranged from 0.38 to 4 kg/ha.day (or 0.59 to 5.57 g EDM/day per individual shrub). The wavy-leaf saltbush was even less productive, growing from 0.01 to 0.46 kg/ha.day of EDM (0.01 to 0.64 g/shrub.day). The peak biomass growth times ware in autumn and early winter.

Comments from Michael Lloyd, host producer

By 2000, 40% of "Bundilla" had become saline and we had revegetated over 600ha with saltbush. It became obvious that with increasing sheep numbers, we had too much feed on the saltland to just use it as to fill the autumn feed gap – there needed to be other opportunities to use this at other times of the year. Subsequently, the Happy Valley Saltland Pastures Group applied for assistance from SGSL to demonstrate a rotational grazing system using the saltbush-based pastures on a year round basis. This was picked up by SGSL and developed into this current project.

This research project has given us the confidence to increase the grazing of the saltland pastures from just autumn to spring. The 2004 results showing an increase in production with rotational grazing suggests to us that higher stocking rates and "harder" grazing will increase production. In addition, the research has supported our observations that heavier stocking rates for short periods (crash grazing) may lead to better pasture composition and a more sustainable system.

Members of our group are now keen to "push the boundaries" in developing different grazing patterns for saltbush-based pastures including, a) intensive grazing at the break of the season – even feedlotting on the saltbush – to let annual pastures get away, or b) grazing heavily in spring just before annual pasture seed set, or c) using stubble and crop residues to supplement the saltbush in late autumn/early winter.

Clearly, we are now seeing more opportunities opening up for the sustainable productive use of saltland pastures. The many farmers who visit "Bundilla" throughout the year appreciate the value of the research being done and gives them confidence to develop their own saltland grazing systems further.

"Saltland is Australia's last opportunity to significantly increase sustainable agricultural production"

Introduction

Dryland salinity is a major threat to agriculture in southern Australia. In Western Australia alone it is now believed that there are between 1.0 and 1.2 million ha of severely salinised land and between 2.8 and 4.4 million ha of land with a high hazard of secondary salinity (Macfarlane *et al*. 2004). Dryland salinity is caused by infiltration of rainfall below the root zone of the annual crops and pastures that are sown on land that was once covered in native perennial vegetation (Turner and Asseng 2005). Water infiltration beyond the root zone (recharge) leads to rising water tables which in turn dissolve salts in soil and bring them to the soil surface (discharge). A large range of perennial plant species have the potential to produce biomass, increase biodiversity and improve the visual amenity of saline land (Masters et al. 2004, Rogers et al. 2003). Halophytic chenopods such as saltbushes (*Atriplex* species) are planted on an estimated 30 000 ha of saline and waterlogged soils in south-western Australia, predominantly in the low to medium rainfall (300-500mm annual rainfall) mixed crop and livestock zone (Barson and Barrett-Lennard, 1985). Being both perennial and active in the summer and autumn, saltbushes also have the potential to reduce the recharge of water tables in the discharge zones. It is unclear however if saltbushes produce enough feed of sufficient quality to justify costs of establishment for livestock systems. The aim of this study was to develop a greater understanding of plant growth and quality, livestock production and environmental sustainability of a saltbush-based saline pasture in southern Australia.

A number of past studies question the biomass production and feeding value of saltbushes and there are many examples in the literature of sheep not maintaining liveweight when grazing saltbush-based pastures (Wilson 1966, Pol 1980, Warren and Casson 1992 and Morecombe *et al.* 1996). Biomass production from saltbushes growing on saline land (rather than non-saline land irrigated with saline water) can be as poor as 0.48 to 0.92 t/ha of 'edible' (leaves and stems < 3mm diameter) dry matter (Warren *et al.* 1994, Wilmot and Norman 2006). The little biomass that is produced by saltbushes is also thought to have poor feeding value. Feeding value is the sum of nutritive value (animal production response per unit of feed intake) and voluntary feed intake and variation in voluntary feed intake accounts for at least 50% of the variation that is observed in feeding value of 'typical' forages (Ulyatt 1973). Voluntary feed intake may play an even larger role in animal performance from saltbush-based pastures than from annual pasture systems. There is no published data describing diet selection in sheep grazing saltbush-based diets but animal house studies and field observations suggest that sheep will limit voluntary feed intake of saltbush. Factors likely to limit the voluntary intake of saltbush biomass include low digestibility, high salt and the presence of secondary plant compounds (Norman *et al.* 2004, Masters *et al.* 2006). It is now believed that the annual plants that grow between saltbushes are the key to animal performance from saline land as they produce biomass that has low salt, perhaps higher energy and offers an alternative without the same secondary compounds.

Despite the limitations of saltbush as a fodder, farmers in south-western Australia continue to plant it in saline areas. This is associated with the high relative value of green feed during the autumn feed gap in mediterranean-type climates. At this time annual crops and pastures are dead and the nutritional value of senesced biomass is poor. The cost of carrying sheep and cattle through periods of feed shortage is a major limitation to profitability of mixed farming systems in southern Australia. Pasture available in autumn or early winter therefore has a higher *marginal* value than herbage produced in the spring. Economic modelling indicates that an additional kg of pasture produced in the wheatbelt in May has 10 times the value of a kg of equivalent quality feed in October (Morrison and Bathgate 1990). Therefore, perennial pasture species that provide a relatively small quantity of biomass when the marginal value of pasture is high could be more profitable than annual species that provide a larger number of total grazing days but with most of the production in spring when there is a surplus of feed.

Complementarity between saltbush and low quality roughage has been demonstrated in several feeding trials with pen-fed animals. Warren *et al.* (1990) found that sheep fed a 1:1 mixture of hay (DMD of 57%) and saltbush, ate 1.5 kg of dry matter per day, significantly higher than the intake of sheep eating hay alone (0.9 kg of dry matter per day) or saltbush alone (0.7 kg of dry matter per day). On the mixed diet, sheep gained 70 g/day but on hay alone or saltbush alone they lost 25 and 225 g/day respectively. It has been postulated that the two limitations to intake (salt and fibre) operate independently of each other (at least partially) so sheep could eat saltbush until they reach a salt intake limit then eat a large quantity of additional roughage as saltbush is low in fibre (Masters *et al.* 2005).

Currently farmers tend to set-stock saltbush based pastures at relatively low grazing pressures, allowing animals to choose their diet. The result is rapid weight gain followed by weight loss as the animals select the most nutritious components of the diet first. Previous research (Norman *et al.* 2002) suggests that sheep will eat the most preferred species in the sward despite the potential benefits to their nutritional status by grazing the saltbush together with the under-storey. Recent work by Thomas *et al.* (2006), where sheep were fed high salt diets with a range of low salt alternatives in an animal house, suggests that sheep may not eat the low salt alternative if it has a dry matter digestibility below 52%. Additionally, if the dry matter digestibility of the low salt feed is above 60%, the sheep will only eat small amounts of the salty diet. This suggests that providing animals with a large quantity of saltbush and understorey may not result in the optimal use of the resource for animal production and grazing management may be important.

We propose that intensifying the grazing management of saltbush-based saltland pastures may improve the long-term nutritional status of sheep by limiting the opportunity to selectively graze components of the diet with the highest feeding value (either saltbush in autumn or understorey in spring). Rotational grazing of saltland pastures may also increase productivity of the understorey by allowing it to recover from predation and maintain optimal leaf area for photosynthesis. If grazing the system in spring, rotational grazing should also reduce selective grazing of the most nutritious pasture annual plant species when they are flowering and setting seed. .

The hypothesis tested in this experiment is that rotational grazing of saltbush-based saline pastures will increase sheep productivity per hectare (total grazing days) and improve both liveweight gain and wool production per hectare over set stocking. Currently, producers tend to graze saltland only during the autumn feed gap. As salinity increases however it is likely that larger numbers of producers are going to have enough saline land that they will need to graze it at other times of the year. This research project investigates animal performance, diet selection and plant productivity of saltland pasture systems during winter and spring

Materials and Methods

Location and layout of experimental plots

The experiment was conducted at ‘Bundilla’, a property 350 km SE of Perth, near the town of Lake Grace. The property was originally settled in the 1920’s but most clearing of native perennial vegetation did not occur until the 1960’s. By the mid 1970’s dryland salinity was becoming a problem and by the 2000, 40 % of the 2000 ha property was salt-affected. Mean annual rainfall for the ten years prior to the experiment was 331 mm (Figure 1).

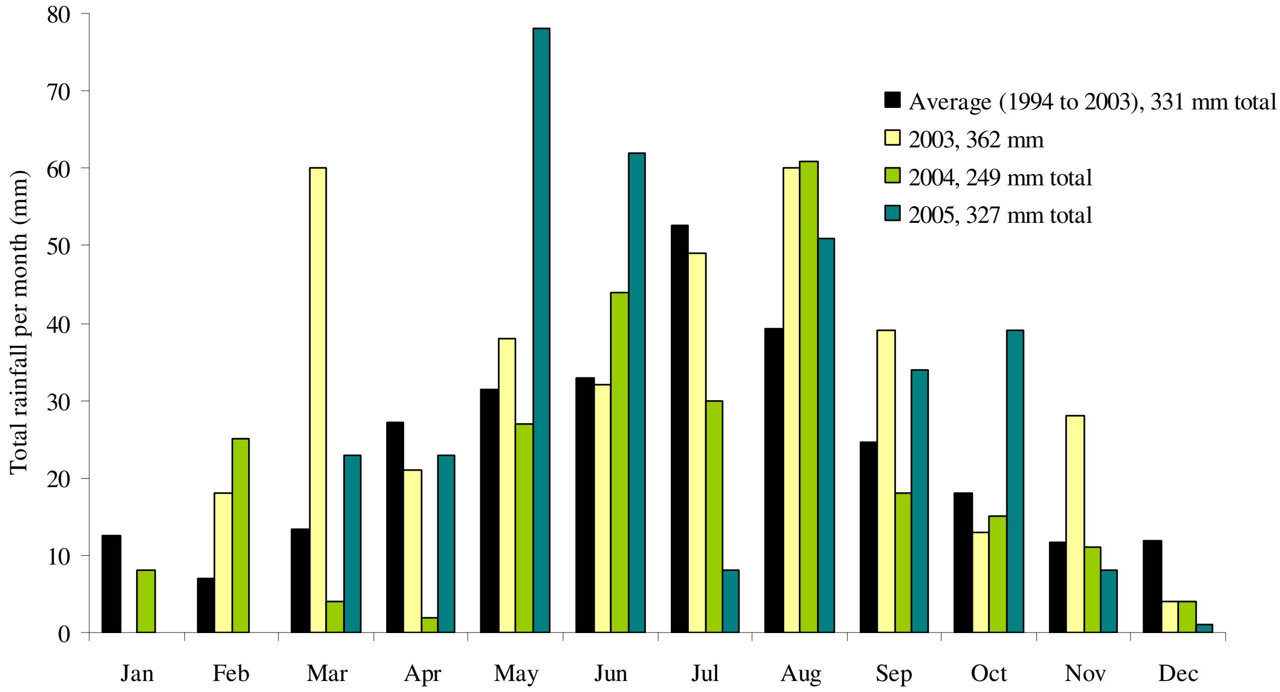
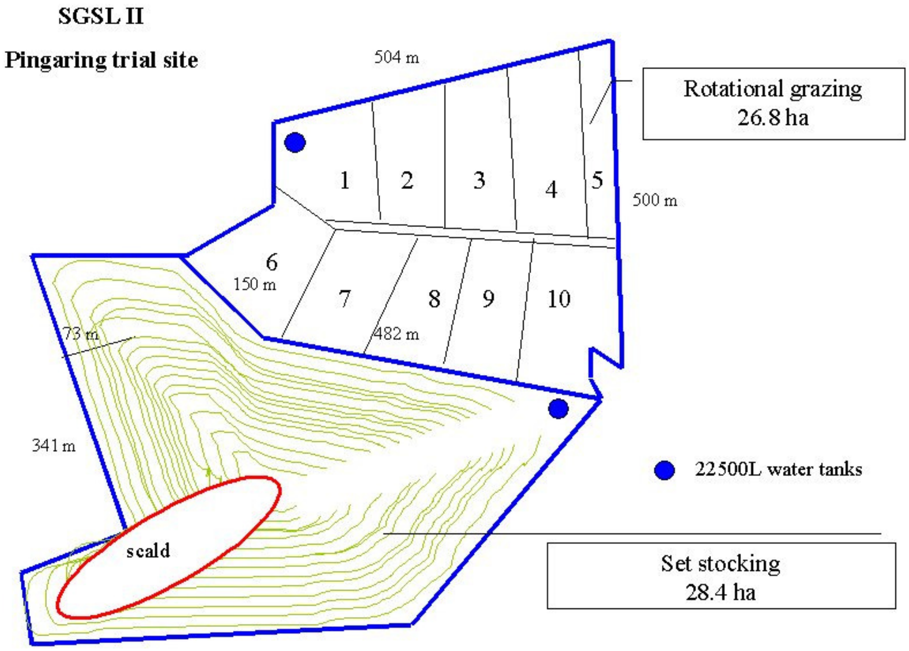


Figure 1. Rainfall at the research site in 2003, 2004 and 2005 and the 10 year average.

The experimental site consisted of 52 ha of mildly salt-affected soils above an extremely saline water table (7500 mS/m and pH of 5.5 on 14/10/04). Saltbush belts (10-13m apart) consisting of old man (*Atriplex nummularia*) and wavy-leaf saltbush (*Atriplex undulata*) were sown on the site in 1999. In 2003, a mixture of balansa clover (*Trifolium michelianum*), subterranean clover *(Trifolium subterraneum)*, burr medic *(Medicago polymorpha)*, yellow serradella *(Ornithopus compressus)* and Italian ryegrass *(Lolium multiflorum)* were sown on the site and allowed to naturalise

To test the hypotheses, the 52 ha area was divided in half. One half was left as a set stocking area while the other was divided into 10 subplots of 2.5 ha each with a central laneway (rotational grazing area). Both areas were grazed from summer to late spring in 2004 and 2005. For the rotationally grazed area, a single mob of sheep was moved between the 10 plots; i.e. all of the animals are in one plot at any time so that 9 plots are spelled. The time of sheep movement was determined by pasture availability and by the life stage of the annual understorey plants. In autumn, sheep were left in a plot until nearly all of the biomass had been consumed (2 to 3 weeks in each plot). In winter, sheep were rotated quickly to allow them access to as much feed as possible while minimising the damage to the germinating understorey (3 to 7 day rotation) and in spring the rotation was fast to minimise heavy grazing of the understorey during seed set (3 day rotation).



Animal performance

In the first year (2004), both plots were initially stocked with 7 Merino wethers/ha from the 14 January. On the 18 March, some sheep were removed so that the set-stocked paddock was grazed with 4 Merino wethers/ha and the rotationally-grazed area was stocked with 7 Merino wethers/ha. Each plot contained 3.8 weaner Merino wethers/ha (approximately 5 months old), and due to shortages of sheep, the balance consisted of hogget Merino wethers. Sheep were on the plots continuously from 14th January until 30 September 2004 (a total of 259 days).

In the 2005 both grazing areas were stocked with 7 weaner Merino sheep per ha (mixed ewes and wethers) from 10 March through until 14 November (total of 251 days). In both years, a subset of 50 weaner wethers within each grazing treatment were used for monitoring liveweight and condition score (Suiter 1994), measured every 14 to 30 days for the duration of grazing. Animals were not fasted before weighing (either before or during the trial) and were weighed within 1 hour of removal from their plot. Of the 50 ‘core’ animals, 20 were used to estimate wool growth per day using the dyeband technique described by Landlands and Wheeler (1968). Fleece weight of core animals was recorded at shearing (after animals had been removed from the plots) and a mid-side sample was taken for estimating yield, fibre diameter and staple strength. Before introduction to the plots all animals were given an anthelmintic drench, selenium slow release bullet and were vaccinated with Glanvac™ 6 (CSL Ltd Victoria) according to the manufacturer’s recommendations. Table 1 lists animal measurements and how often they occurred. Sheep had access to unlimited fresh drinking water at all times during grazing. In 2004, the animals were supplemented for a short period after they started to lose weight. The sheep in both treatment plots received 150 g/head of barley grain fed twice per week from April 26 to 24 May.

Plant biomass and botanical composition

Plant composition, soil cover and biomass were determined on a monthly basis in the set stocked plot as well as immediately prior to and after grazing in the rotationally grazed plots (see Table 2). All biomass measurements were obtained from 'w' shaped transects within plots. Understorey biomass, vegetation cover and botanical composition were assessed using calibrated quadrat cuts and the dry-weight-rank method of Mannetje and Haydock (1963). Prior to grazing, individually numbered permanent transects of 10 m in length were randomly allocated within the saltbush rows. Each of the 10 rotationally grazed plots contained 5 saltbush transects and the set stocked plot contained 10 saltbush transects. Saltbush edible dry matter was estimated using the 'Adelaide' technique of Andrew *et al.* (1979). This is a non-destructive comparative ranking technique where a branch representing approximately 20% of a typical shrub is compared to other shrubs within transects. The representative branch is then striped of all leaves and small stems (<3mm) and the material is dried at 65^{o}C for 48 hours. The mean shrub rankings within transects are then multiplied by the dry material in the branch and saltbush numbers to estimate saltbush 'edible dry matter' (EDM). Saltbush numbers in each transect were counted each time biomass was estimated.

Nutritive value

Plant species that contributed more than 5% of total biomass within a plot were tested for *in vitro* nutritive value each spring and each autumn immediately prior to grazing. Samples of the 'edible' component (leaves and small stems < 3mm in diameter) of each plant species were collected across the plots, placed in a paper bag and dried at 65^{o}C for hours. The oven dried samples were then ground to pass through a 1mm screen using a Tecator Cyclone© mill. Unless indicated, all samples were analysed and each sample performed in duplicate.

Table 1. List of experimental measurements for animals, time of implementation and references

Measurement	Method & reference	Rotational plots	Set stocked plot
Individual liveweight (kg)		Start and end of grazing each year and monthly when sheep were on the plot	Start and end of grazing each year and monthly when sheep were on the plot
Condition score	Suiter 1994	Start and end of grazing each year and monthly when sheep were on the plot	Start and end of grazing each year and monthly when sheep were on the plot
Seasonal wool growth	Dyeband procedure as described by Langlands and Wheeler (1968)	Start and end of grazing and every 2 months when sheep were on the plot	Start and end of grazing and every 2 months when sheep were on the plot
Fleece weight	Weigh individual fleeces, unskirted, without bellies	At shearing	At shearing
Wool quality	Midside wool sample from 50 sheep per treatment. Analysed for fibre diameter, yield, staple strength, position of the break and fibre diameter profile	Collected at shearing	Collected at shearing
Drinking water quality	Measure salt concentrations in drinking water	2-3 times per year	2-3 times per year
Faecal egg count	Faecal samples from 15 sheep per treatment, bulked	Before grazing, approx. every 2 months during grazing	Before grazing, approx. every 2 months during grazing

Organic matter (OM), total and soluble ash was determined on plant samples as described by Faichney and White (1983).

Digestibility (pepsin-cellulase digestion of the organic matter or P-COMD and pepsin-cellulase digestion of the organic matter in the dry matter P-CDOMD) was estimated using the pepsin-cellulase digestion method described by (Klein and Baker 1993). A range of standards with known *in vivo* digestibility were used to calibrate the raw pepsin-cellulase digestion data. However it must be noted that none of these *in vivo* standards were halophytic plants. As salt has been shown to reduce *in vivo* digestibility of feed (Masters et al. 2005) it is likely that the *in vitro* figures presented for saltbush, blue bush and samphire are over estimates of *in vivo* digestibility. The information presented in this study is useful for comparing halophytic plants but values are not absolute and should not be extended outside the context of this paper.

Neutral detergent fibre (NDF) was measured using an Ankom 200/220 Fibre analyser in accordance with the operating instructions for this equipment. Sub samples of the dried and ground material were digested for 60 minutes, using a neutral detergent solution, in an ANKOM200/220 Fibre Analyser (Ankom ® Tech. Co., Fairport, NY, USA). This was used to dissolve the easily digested pectins and plant cell components (proteins, sugars and lipids), leaving the fibrous residue (cellulose, hemicellulose and lignin). Acid detergent fibre (ADF) was measured using an Ankom 200/220 Fibre analyser in accordance with the operating instructions for this equipment (Ankom ® Tech. Co., Fairport, NY, USA). ADF was determined sequentially on the samples previously used for NDF. The samples were digested in an acidified quaternary detergent solution to dissolve remaining soluble cell components, hemicellulose and soluble minerals. Again digestion occurred in an ANKOM 200/220 Fiber Analyzer over 60 minutes.

Table 2. List of experimental measurements for animals, time of implementation and references

Measurement	Method & reference	Rotational plots	Set stocked plot
Pasture mass (kg DM/ha)	Calibrated visual estimation of quadrates within a random 'W" shaped transect bisecting the whole plot	Start and end of grazing each year and every time sheep move into or out of a subplot	Start and end of grazing each year and monthly when sheep were on the plot
Green and dry pasture (kg DM/ha, %)	Calibrated visual estimation taken within pasture mass quadrates	Start and end of grazing each year and every time sheep move into or out of a subplot	Start and end of grazing each year and monthly when sheep were on the plot
Pasture composition (kg DM/ha, %)	BOTANAL (Tothill et al 1992) incorporating dry-weight-rank technique (Mannetje and Haydock 1963), taken within pasture mass quadrates	Start and end of grazing each year and every time sheep move into or out of a subplot	Start and end of grazing each year and monthly when sheep were on the plot
Presence of all pasture species	Visual assessment within pasture mass quadrates	Start and end of grazing each year	Start and end of grazing each year
Shrub density (plants/ha)	Direct measurement within permanent transects	Start and end of grazing each year. 5 permanent transects of 10m within each sub-plot were used for all shrub assessments	Start and end of grazing each year. 10 permanent transects of 10m within the set-stocked plot were used for all shrub assessments
Shrub mass (kg DM/bush and kg DM/ha)	`Adelaide technique' of Andrew et al. (1979). Within permanent transects	Start and end of grazing each year (all subplots) and when sheep are introduced or removed from a sub-plot.	Start and end of grazing each year and monthly when sheep were on the plot
Shrub composition (%)	Direct assessment of shrubs within permanent transects	Start and end of grazing each year	Start and end of grazing each year
Pasture and shrub quality	NIR/wet chemistry (IVD, N, NDF, ash, salt). Pasture samples collected by the 'toe-cut' method.	Start and end of grazing each year and every time sheep move into or out of a subplot	Start and end of grazing each year and monthly when sheep were on the plot

Mineral analyses were conducted by a commercial laboratory (Wesfarmers CSBP Limited). Only one sample of each plant species in spring and autumn were analysed. Total N was determined by combustion using a Leco FP-428 N Analyser (Sweeney and Rexroad 1987). Phosphorous (P), potassium (K), sulphur (S), sodium (Na), calcium (Ca), magnesium (Mg), copper (Cu), zinc (Zn), manganese (Mn), iron (Fe) and boron (B) were measured by ICP-AES (McQuaker et al. 1979). Chloride (Cl) and nitrate were measured using a Lachat Flow Injection Analyser by the method of Zall et al. (1959).

Estimating diet selection

On 4 occasions during 2005 (summer, autumn, late winter and spring), faecal samples were collected from 20 sheep in the set stocked plots. The faecal samples and samples of the saltbush and understorey collected on the same day as the faeces, were dried at 65^{o}C and ground to pass through a 1mm screen using a Tecator Cyclone© mill . Carbon isotopes at the natural abundance level were determined using Dumas principles and continuous flow system (Tracermass Ion Ratio Mass Spectrometer and Roboprep preparation system, manufactured in 1997 by Europa PDZ, UK). System calibration was performed using known international ^{13}C references (NBS-19, NBS-18, NBS 22). Internal laboratory standards were calibrated against these international references and Atropine (product code B2002 and Acetanilide B2000 from Elemental Microanalysis Limited, UK) were used to calibrate the system for total C. Analytical Precision (based on multiple replicate analyses) was ±0.2‰ vs. PDB for Delta^{13}C and ±2.40g/100g C for Total C. Saltbush in the diet was estimated using the following equation;

% Saltbush = 100-(100/((A(C-E)/B(E-D))+1)

Where; A= 100 – OMD of understorey, B= 100 – OMD saltbush, C= δ13 of the understorey - 1, D= saltbush - 1 and E= δ13C of the Faeces

Results

Animal production

During the course of the experiment each year, the young sheep grew between 22 and 30 kg in weight (Figure 2). In 2004 and 2005, the mean growth pattern of the animals was similar. After introduction to the plots in late summer, the sheep initially demonstrated modest weight gains before reaching plateau in April, May and early June. The animals then grew rapidly from mid winter each year through until their removal from the plots in late spring. In 2003, the set stocked animals were marginally heavier (~2kg) than the rotationally grazed animals for most of the grazing period, however they had similar mean liveweight when they were removed from the plots at the end of September. There were few liveweight differences between the flocks grazing the plots in 2005, the sheep from the rotationally grazed plots were marginally heavier at the end of grazing. Figure 3 illustrates the mean condition scores of the sheep. Condition scores follow a similar pattern to liveweight change.

The sheep averaged from 11 to 17.4 kg/ha of clean wool growth when on the saltland pasture plots (Table 3). In 2004, the sheep on the rotational plots grew 4.6 kg/ha more wool than the sheep on the set stocked plots where the stocking rate was lower. The sheep on the set stocked plots produced stronger wool with a slightly higher fibre diameter. In 2005, the sheep in the rotational plots grew the same quantity (17 kg/ha) of quality wool however the wool from the rotatiooal plots was 7.6 N/ktex.

Table 3. Wool production from the plots, fleece quality and estimated gross value of wool production per ha of saltland pasture.

Year	Grazing treatment	Clean fleece weight (kg)	Fibre diameter	Staple strength (N/ktex)	Yield (%)	Clean wool/ha	Value of wool (c/kg)*	Est. $/ha*
2004	Rotational	2.53	19.1	23.5	72.4	15.63	827	129
	Set-stocked	3.08	19.7	26.7	72.8	11.01	802	88
2005	Rotational	3.31	21.1	29.2	71.9	17.11	719	123
	Set-stocked	3.34	21.2	21.6	72.3	17.43	684	119

* Estimated value of wool based on Australian Wool Innovation ‘Wool Cheque’ calculator (12 month average in Oct 06, sold in the West).

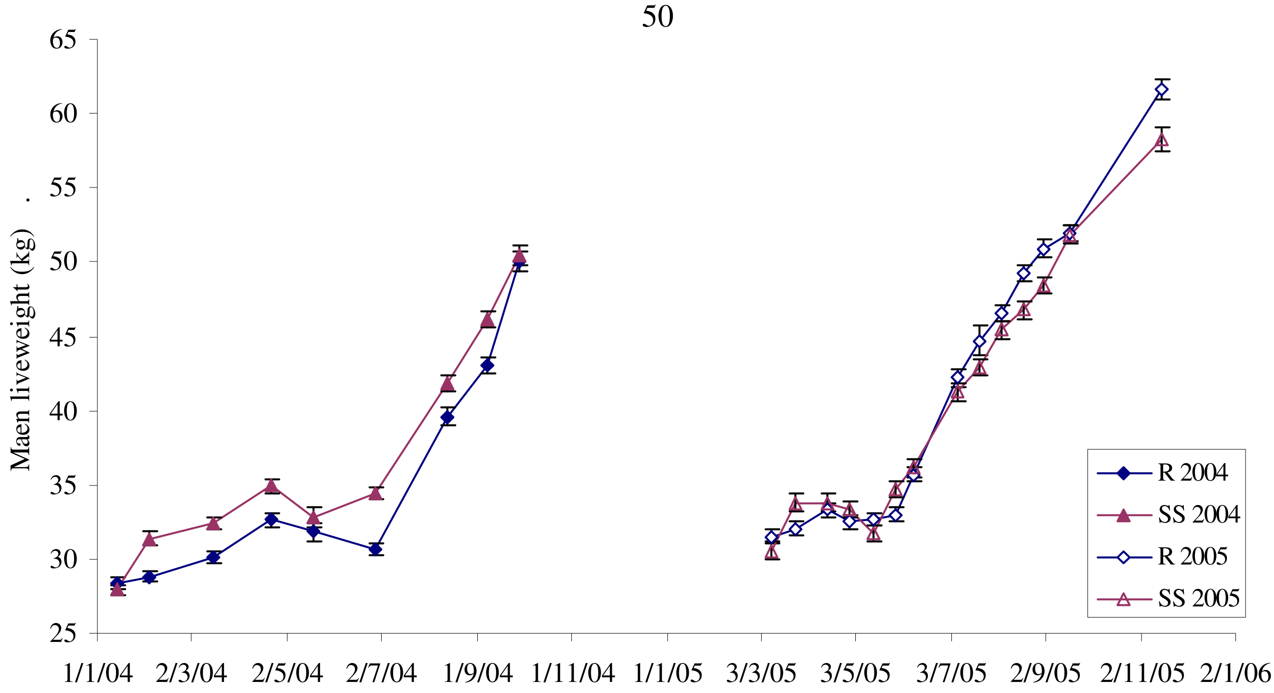


Figure 2. Mean liveweight of young Merino sheep grazing saltland pasture in 2004 and 2005. Each year one flock was set-stocked (SS) and the other rotationally grazed (R). Different animals were used in 2004 and 2005.

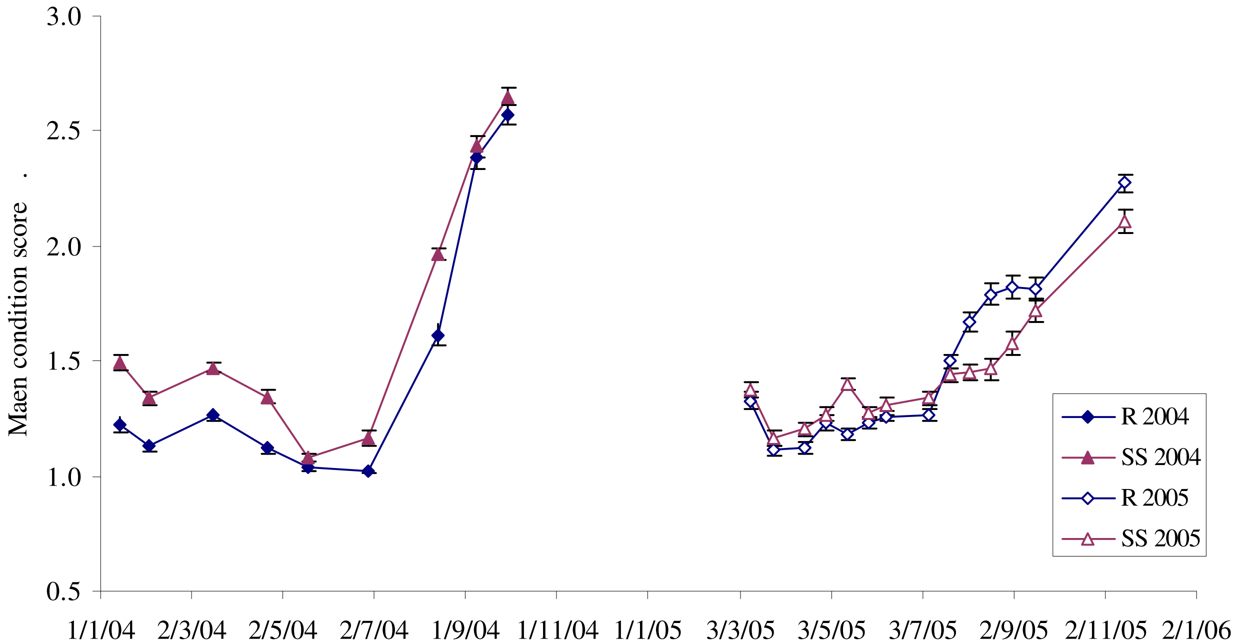


Figure 3. Mean condition score of young Merino sheep grazing saltland pasture in 2004 and 2005. Each year one flock was set-stocked (SS) and the other rotationally grazed (R). Different animals were used in 2004 and 2005.

Pasture production

In 2004 when the trial started, the paddocks contain an average of 800 m of double saltbush rows per ha, equating to an average of 654 old man saltbush plants/ha and 948 wavy-leaf plants/ha. By the end of the second year of grazing there were 638 old man and 575 wavy-leaf plants per ha in the rotational plots and 644 old man and 450 wavy-leaf plants per ha in the set-stocked plots. Both stocking treatments had a detrimental effect on the survival of wavy-leaf saltbush however set stocking killed 34% more shrubs than rotational grazing.

Prior to grazing, in January 2004, there was 2082 kg/ha of under-storey biomass and 469 kg/ha of saltbush ‘edible’ dry matter or leaves and stems < 3mm (EDM) in the rotational plots and 2568 kg/ha of under-storey biomass and 476 kg/ha of saltbush EDM in the set stocked plots. Saltbush EDM represented approximately 16% of the total feed on offer. By the end of September, the plots had 1300 to 1660 kg/ ha of understorey DM remaining and only 77 to 166 kg/ha of saltbush EDM and saltbush represented only 4 to 8 % of EDM. During the summer when there were no animals on the plots, the saltbush continued to grow so that by March 2005, saltbush comprised 18% of the EDM. Again in 2005, saltbush formed only a minor component of total EDM and when the last flock of sheep were removed in November 2005, the set stock plot contained 600 kg understorey DM and 53 kg of saltbush EDM. The rotationally grazed area had 200 kg/ha more understorey and 7 kg/ha more saltbush EDM.

Table 4 biomass on offer (kg EDM/ha) in the set stocked and rotationally grazed plots when sheep were put on and removed from the plots and at peak biomass in 2005.

	Understorey DM		Old man saltbush EDM		Wavy-leaf saltbush EDM		Total EDM		Saltbush % in EDM	
	Rotational	Set stocked	Rotational	Set stocked	Rotational	Set stocked	Rotational	Set stocked	Rotational	Set stocked
Jan 04	2082	2568	306	259	163	217	2551	3044	18.4	15.6
Sept 04	1294	1661	76	48	40	29	1410	1738	8.2	4.4
Mar 05	1789	1643	257	246	138	105	2184	1994	18.1	17.6
Sept 05	2088	1736	24	20	14	23	2125	1778	1.8	2.4
Nov 05	794	602	41	37	19	16	854	655	7.0	8.1

Figure 4 demonstrates the pattern of feed on offer in the set stocked paddock during the grazing periods. As expected, understorey biomass is accumulating in winter and spring (despite 7 sheep/ha grazing pressure) and is depleted in the summer/autumn. Old man saltbush biomass was greater in 2005 than in 2004 despite the higher stocking intensity. It is clear that saltbush provides less feed than the understorey component of the diet.

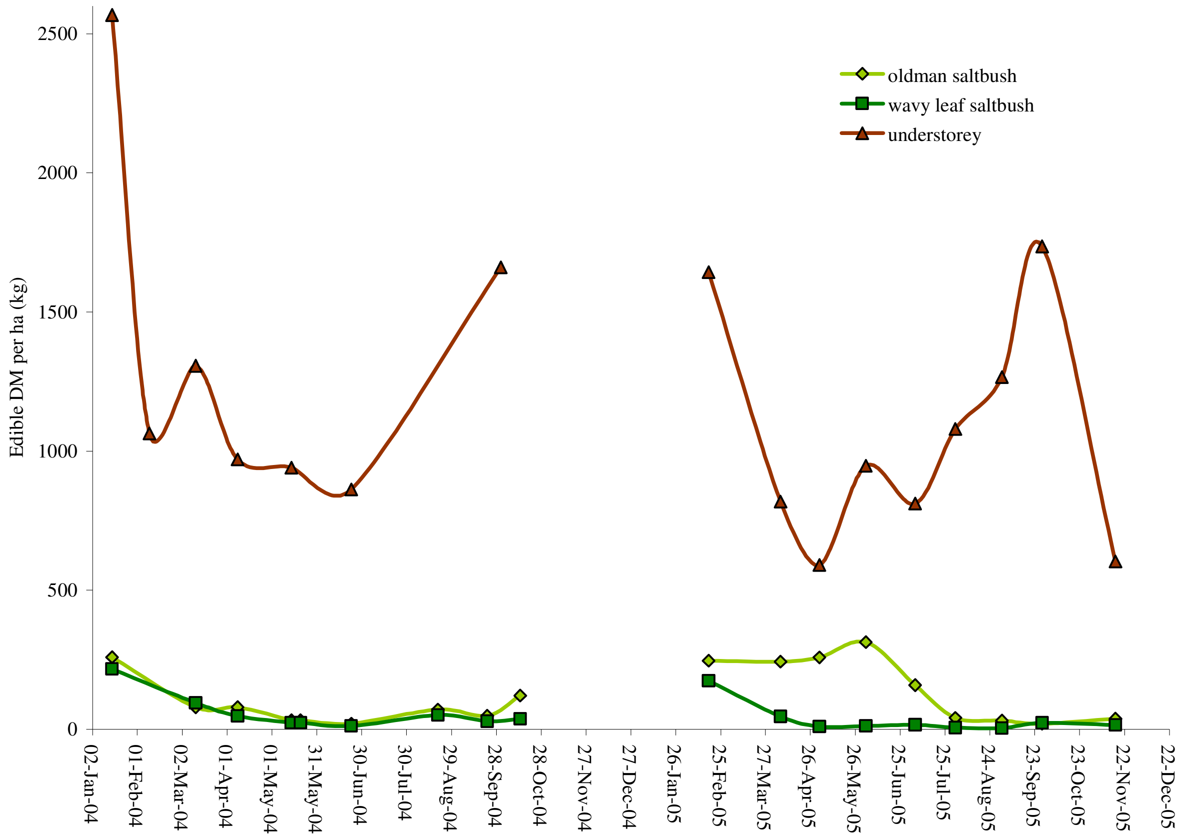


Figure 4. Understorey and saltbush feed on offer (EDM/ha) in the set stocked paddock during grazing in 2004 and 2005

The rotational grazing plots provided a unique opportunity to measure the growth rate of two saltbush species throughout the year in replicated plots. The growth of saltbush in the 9 plots that did not contain sheep allowed robust and replicated measurement of growth from saltbushes at different stages of recovery from grazing. Growth rates of old man and way-leaf saltbush on an individual shrub basis are presented in table 5. The growth rate of old man saltbush EDM ranges from 0.38 to 4 kg/ha.day (or 0.59 to 5.57 g EDM/day per individual shrub). The wavy-leaf saltbush was less productive, growing from 0.01 to 0.72 kg/ha.day of EDM (0.01 to 0.64 g/shrub.day). The growth rate of old man saltbush at different times of the year is illustrated in Figure 5. The peak biomass growth times are in autumn and early winter. The data from 2004 and 2005 indicated that the relative growth at various times of the year was similar however total growth in 2004 appeared to be greater.

Table 5. Growth rates of old man and way-leaf saltbush in the rotationally grazed plots in 2004 and 2005.

		Old man saltbush				wavy-leaf saltbush			
season	Year	Obs[1]	Stems/ha	Daily growth		Obs[1]	Stems/ha	Daily growth	
				kg EDM/ha	g EDM/stem			kg EDM/ha	g EDM/stem
autumn	2004	5	718	4.00	5.57				
	2005	20	630	2.55	4.05	30	691	0.06	0.08
winter	2004	40	699	1.92	2.75	50	715	0.46	0.64
	2005	40	662	1.19	1.80	55	699	0.01	0.01
spring	2004	25	616	0.62	1.00	35	731	0.17	0.23
	2005	35	644	0.38	0.59	30	733	0.24	0.33
summer	2004/2005	50	664	1.30	1.96	50	726	0.72	0.99

[1] Number of 10 m saltbush transects that were used to derive the mean.

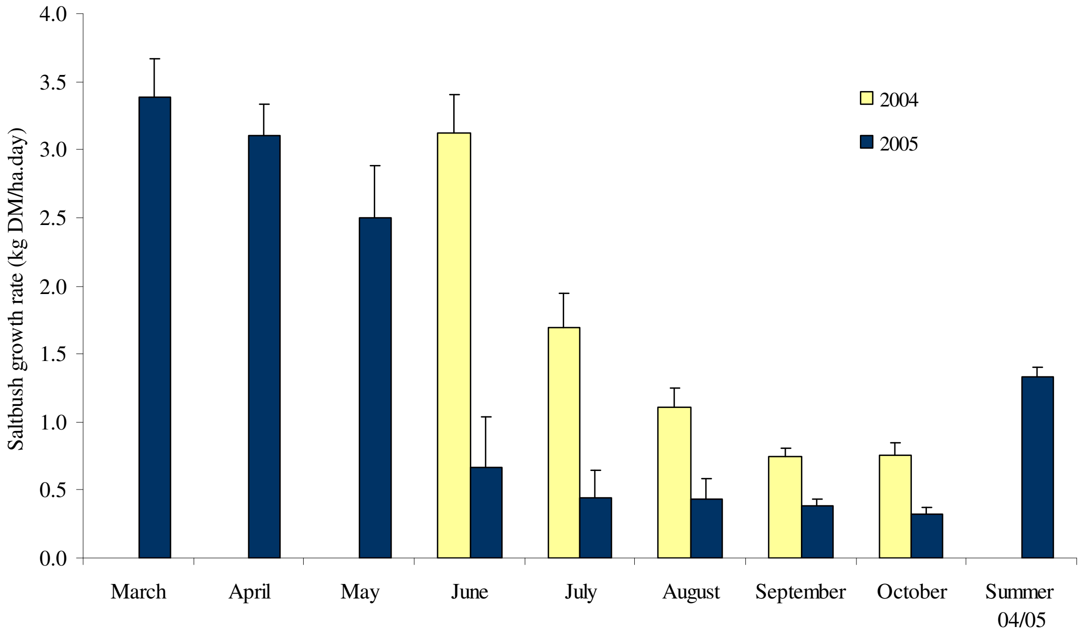


Figure 5. Growth rate of saltbush EDM in the rotationally grazed plots in the absence of sheep. Note 2004 measurements started in June.

Pasture quality

Figure 6 presents the DOMD of the saltbush and understorey species during the trial. The most important observation is that DOMD of both saltbush species does not vary across the season. The little variation that is observed is likely to reflect sampling procedure; i.e. the size stem that was included in the sample. The energy value of the understorey sward ranges from 38 to 72 % DOMD, and this is associated with life stage of the annual species (actively growing vegetative biomass in early spring had higher energy than dead senesced material in autumn).

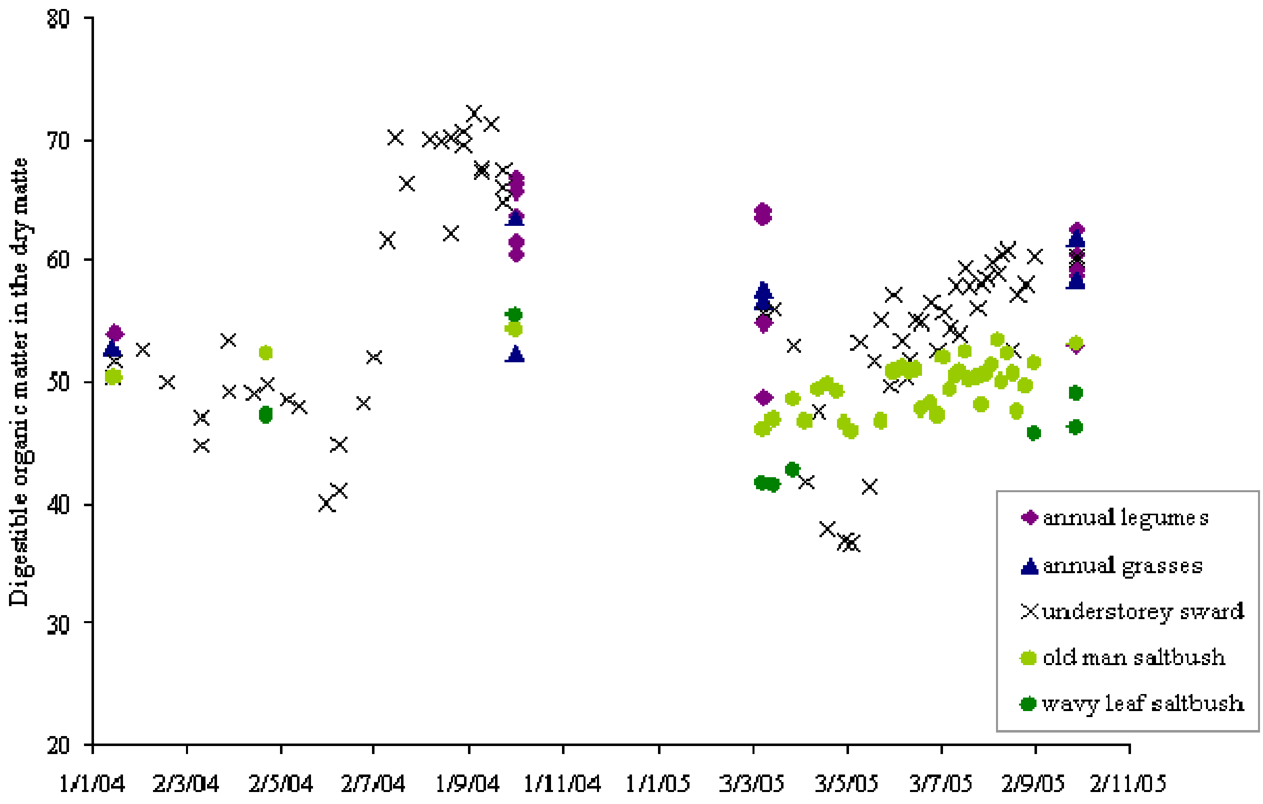


Figure 6. *In vitro* digestible organic matter in the dry matter of saltbushes, annual legumes, grasses and the mixed understorey sward, sampled over 2 years. Note the data for saltbush is an overestimate of in vivo digestibility and should only be used to compare relative digestibility within the saltbushes.

DOMD of the understorey sward at the start of grazing in January 2004 was 51% and the annual legumes (balansa clover and burr medics) had 4% digestibility than the sward average. At the start of grazing, the saltbush had DOMD values that were similar to the sward. From January to June in 2004 and March to June in 2005, the DOMD of the understorey sward declined to a low of 38% while the DOMD of the saltbushes remained static at about 50% for old man saltbush and 45% for wavy-leaf saltbush. The understorey had higher energy than the saltbush after germination. This was not until July in 2004, but occurred earlier in 2005 due to good rainfall in May. It is interesting to note that the understorey sward reached a higher peak DOMD in 2004 than in 2005.

Crude protein of the plants is presented in Figure 7. Both the saltbushes and understorey sward show a dramatic leap in protein during 2005. Given a crude protein requirement of dry sheep about 10%, the understorey sward, wavy-leaf saltbush and grasses are protein deficient from during summer, autumn and early winter while the old man saltbush and annual legumes have sufficient protein.

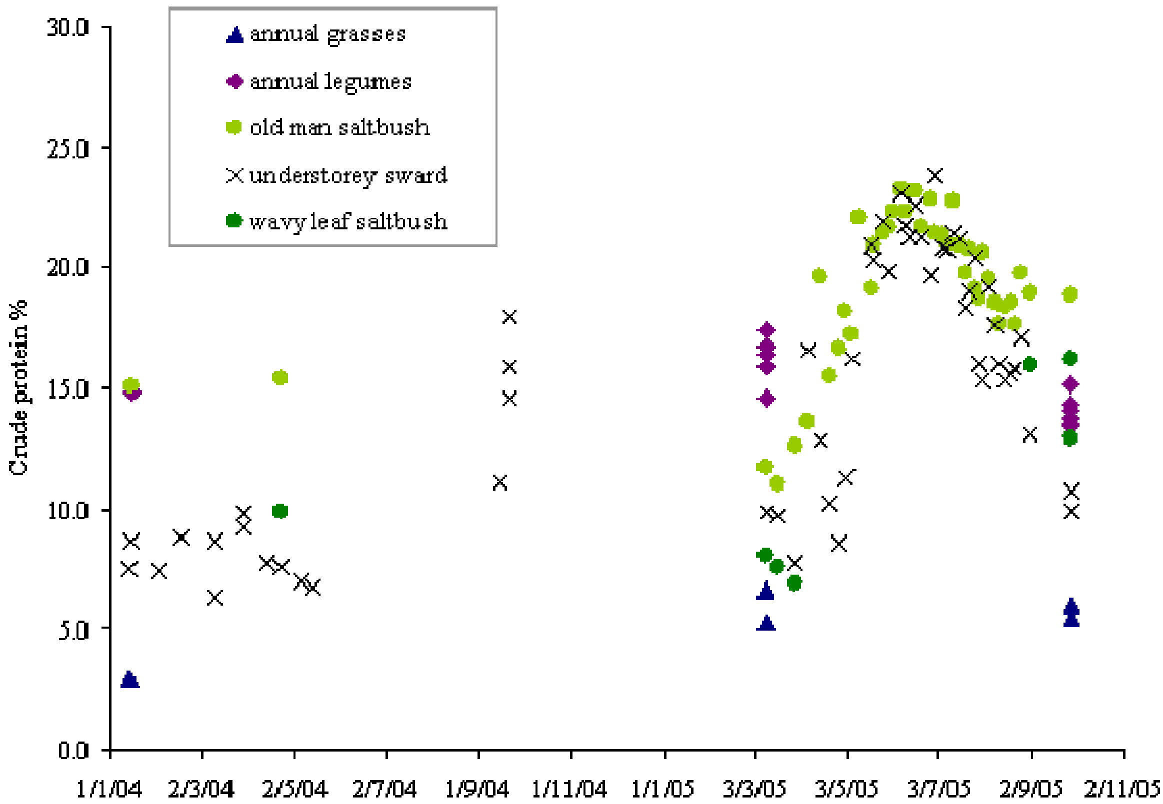


Figure 7. Crude protein (% of EDM) of saltbushes, annual legumes, grasses and the mixed understorey sward, sampled over 2 years.

Figure 8 illustrates the ash content of biomass during the experimental period. Both saltbushes had between 25 to 35% salt in the dry matter while the grasses and legumes tended to have less than 15% salt. It is interesting to note that the understorey sward did accumulate some high levels of salt in winter of each year.

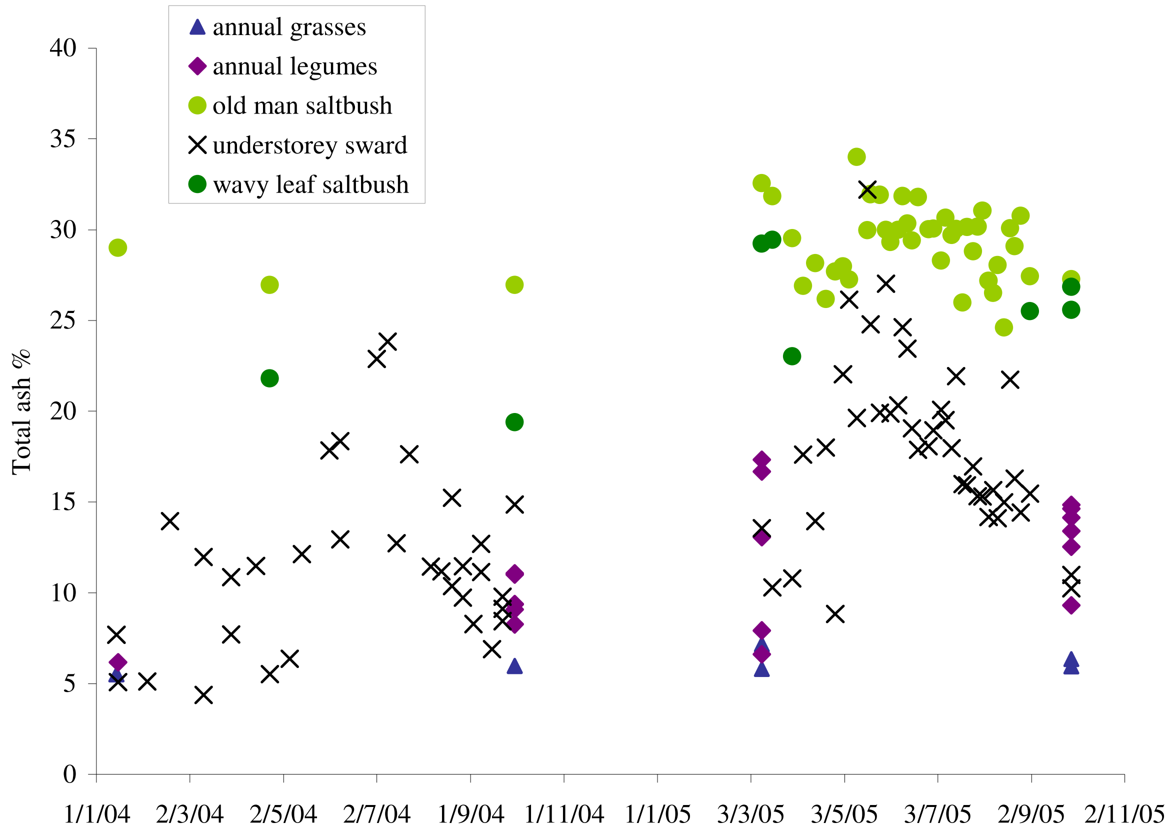


Figure 8. Ash content (% of EDM) of saltbushes, annual legumes, grasses and the mixed understorey sward, sampled over 2 years.

Botanical composition of the understorey sward

Table 6 presents the botanical composition of the understorey sward at the time of estimated peak biomass in spring each year. The understorey was dominated by the annual legumes; balansa clover (approximately 25-35% of dry matter), subterranean clover (11-25%), burr medic (6 to 12%) and woolly clover (6 to 7%). Annual ryegrass (8 to 23%) and barley grass (7 to 10%) were the dominant grass species and capeweed also formed a significant part of the sward (2 to 15%).

Table 6. Botanical composition (% of DM) of the understorey in spring 2004 and 2005

Name	Common name	Peak biomass 2004		Peak biomass 2005	
		Rotational	Set-stocked	Rotational	Set-stocked
Trifolium michelianum	Balansa clover	25.5	34.5	19.6	15.8
Medicago polymorpha	Burr medic	5.5	12.4	7.4	5.6
Trifolium subterraneum	Subterranean clover	25.5	11.3	16.3	7.8
Trifolium tomentosum	Woolly clover	6.3	7.0	18.2	31.8
Trifolium glomeratum	Cluster clover	1.0	1.0	4.7	2.0
Trifolium glanduliferum	Gland clover	0.2			
Medicago minima	Goldfields burr medic	0.5			
Lolium rigidum	Annual ryegrass	22.7	7.9	15.7	2.2
Hordium leporinum	Barley grass	10.1	6.8	5.7	5.7
Parapholis incurva	coastal barb grass		1.3		
Vulpia myuros	silvergrass	0.1		0.1	
Arctotheca calendula	capeweed	2.0	15.3	9.2	19.4
Plantago coronopus	Plantain	0.1	2.0	2.8	7.8
Heliotropum curassavicum	Heliotrope	0.1			
Rumex spp.	Sorrell	0.3	0.5	0.3	1.3
Cotula bipinnata	ferny cotula				
Hypochaeris radicata	flat weed	0.3		0.1	0.6
Erodium botrys	erodium	0.1		0.1	
Total legumes		64.5	66.2	66.2	63.0
Total grasses		32.9	16.0	21.5	7.9
Total forbs		2.9	17.8	12.5	29.1

Diet selection by animals

The estimated proportion of saltbush in the diet, predicted using the δ13C technique is presented in Table 7. It must be noted that the winter sampling was in late winter when the understorey was green and actively growing. Sheep ate a higher proportion of saltbush in the diet when the digestibility of the understorey was lower, peaking at an average of 52% saltbush in the diet in autumn. Given diet composition, digestibility and protein of the components, we can use the ruminant nutrition model GrazFeed (Freer *et al.* 1997) to predict total dry matter intake and salt intake. Predictions of daily intake range from 840 g DM/day in autumn when animals are maintaining liveweight to 1460 g DM/day in spring where animals are growing at 108 g/head.day. In autumn the animals were ingesting a predicted average of 114 g of salt per head.day. There was considerable variation in diet selection between animals in the same plot (Figure 9). In autumn, one animal in the rotationally grazed plots was eating only 25% saltbush while other animals in the same plot consumed up to 68% saltbush.

Table 7. Estimated diet selection by sheep in autumn, winter, spring and summer (2005 animals)

Season	Mean δ13C in faeces	OMD of alternatives saltbush %	legume %	Estimated Saltbush diet (%)	Sheep growth (g/day)	Predicted DM intake (kg/day)	Predicted salt intake (g/day)
Autumn	-22.8	55	50	52	1	0.84	114
Winter	-24.8	55	85	24	147	1.29	82
Spring	-26.9	55	75	11	108	1.46	42
Summer	-24.3	55	60	34			

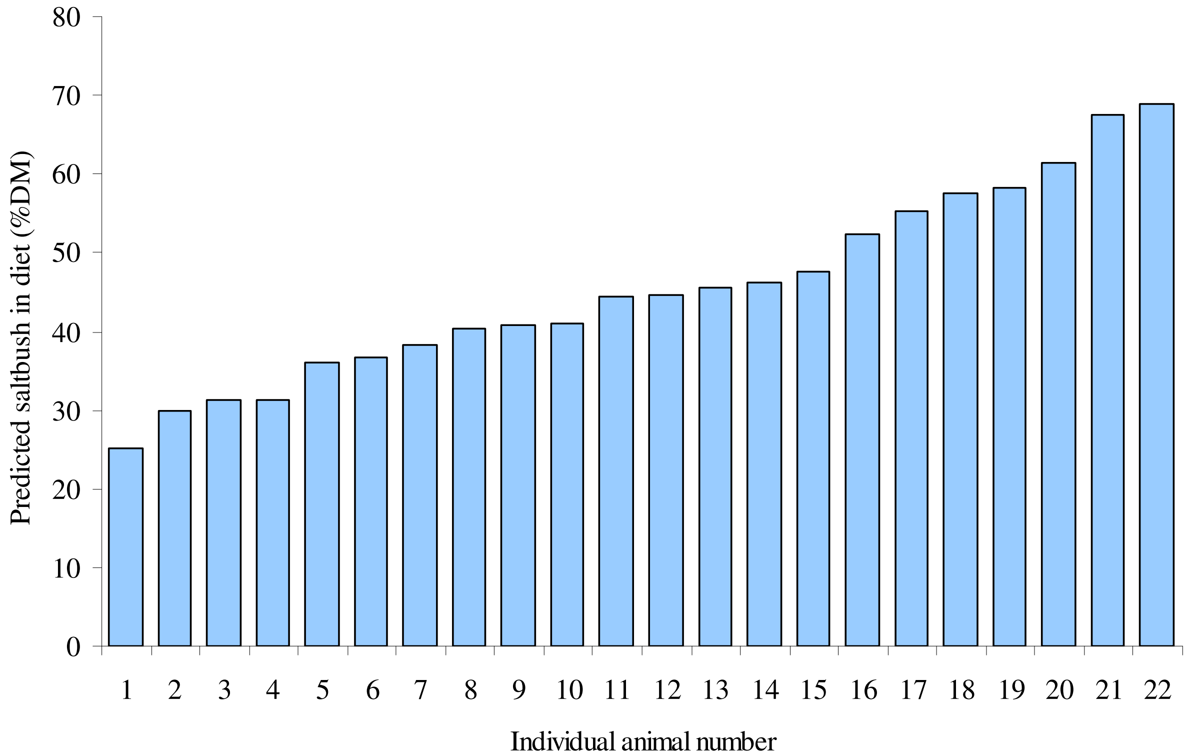


Figure 9. Saltbush intake as a proportion of total diet (estimated using the δ13C technique) for individual animals from the same plot in autumn 2005.

Figure 10 is a chart modelling the productivity of saltbush based on the 2004 productivity data. The model predicts growth of old man saltbush at 3 planting densities and wavy-leaf saltbush at a single planting density.

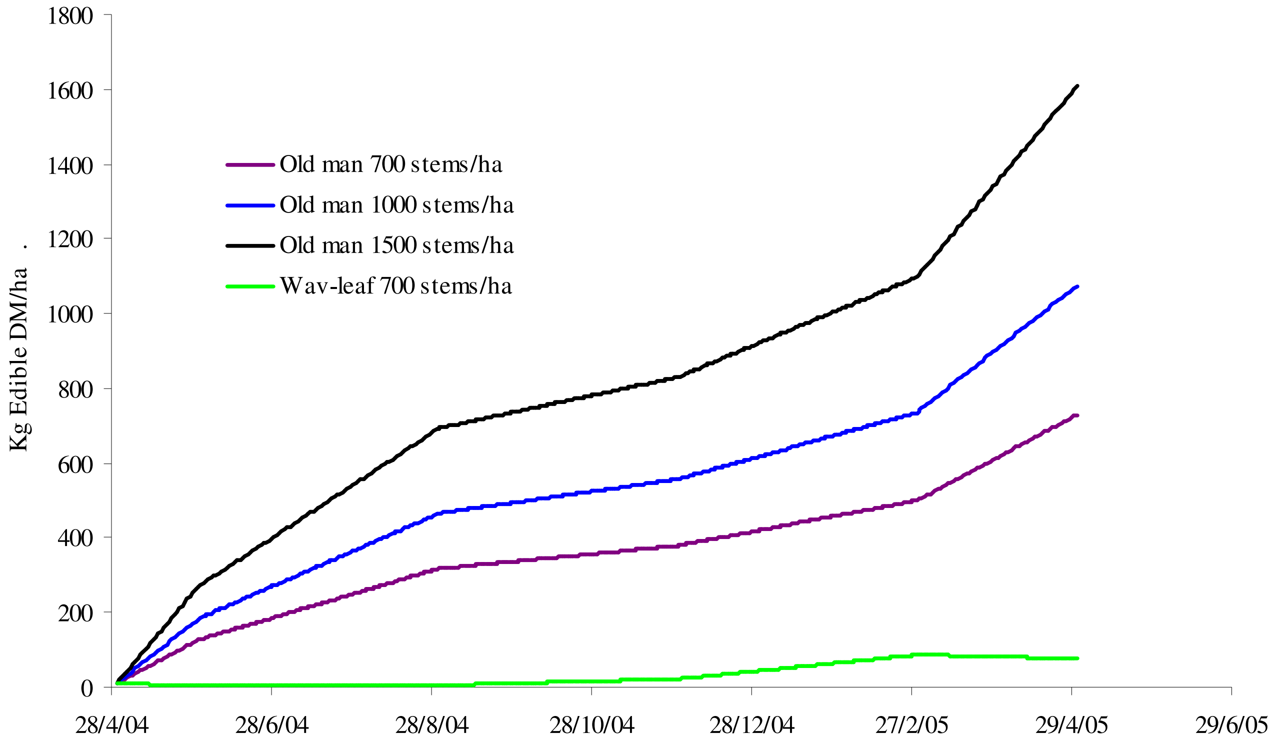


Figure 10. Hypothetical production curves of saltbushes at different plant densities, based on growth rates at Pingaring in 2004.

Discussion

Saltbush pastures, consisting of wide spaced rows of saltbush with a sown legume understorey are capable of supporting 7 growing animals per ha for nine months of the year on mildly saline land in the low rainfall wheat belt of Western Australia (330 mm annual rainfall). This stocking rate is higher than district average stocking rates for pastures that are not salt-affected (M. Lloyd pers comm.). There is also evidence that the saltbush uses water and helps to keep the saline water table below the root zone of plants (Barrett-Lennard and Altman – unpublished research from adjacent site). During Autumn and early winter the pasture provides only a maintenance diet however when the understorey components of the system are active and have high nutritive value, animals can grow at a rate of more than 300g per week. Over the experiment the sheep produced from 11 to 17.4 kg of clean wool/ha per year with an approximate value of between $88/ha to $129/ha (based on 12 month average prices in 2006). Currently, producers tend to graze saltland only during the autumn feed gap. The hypothesis, that animals can achieve growth when grazing salt-bush alley pasture systems in spring was supported by the data. Although it is economically more sensible for producers with a small amount of saline to graze it during the autumn feed gap (O'Connell and Young, 2002), farmers with large areas of mildly saline land can use it to achieve animal growth during spring.

The animal production data yields mixed messages regarding the added value of rotational grazing of saltland pastures. In 2004, when the rotational area was stocked with an additional 3 sheep/ha, the rotationally grazed animals reached the same liveweight and condition score as the animals in the set stocked paddock by the end of September. In 2005 when both areas were stocked at the same rate of 7 sheep/ha the differences in animal productivity were small. There only an extra 3.5kg/head liveweight gain in the sheep that were rotationally grazed. The animals in the rotational plots produced an extra 0.22 kg of clean wool per ha with higher strength, resulting in $4/ha higher gross value of the wool (based on 12 month average prices in October 2006, sold in the west). There were several positive outcomes from rotational grazing in terms of the pasture. After grazing in 2005, the rotational plots had marginally more biomass remaining, in spring 2005 the rotational plots had greater legume composition and less capeweed and finally, rotational grazing killed less wavy-leaf saltbushes than set stocking. While we hypothesised that we could flatten out the rapid liveweight gain/rapid liveweight loss of sheep that are set stocked in saltland in autumn by reducing selective grazing, we did not find that rotational grazing led to a different pattern of growth during autumn.

It is possible that we may have had a different result if we had grazed both plots with 7 sheep/ha in 2004 and 3 less sheep/ha in the set stocked plots in 2005. In 2004, the site received only 70% of average rainfall whereas 2005 was an average rainfall year. In effect, we may not have pushed the system hard enough in 2005 and may have found a difference associated with rotational grazing if we had stocked the plots with more sheep/ha. Overall however, the difficulty we had in detecting a difference between the grazing treatments suggests that the extra time and fencing involved in rotational grazing may not be justified in terms of returns from the animal production system.

While the data did not support our primary hypothesis, we have developed a much greater understanding of saltbush in production systems. Prior to this research project very little was known about saltbush growth rates of mature saltbushes in the field, changes in nutritive value over time and diet selection by sheep grazing saltbush.

As we would expect, sheep eat more saltbush when the digestibility of the understorey is lowest and animals vary in the amount of saltbush they choose to eat. We did not expect that the sheep would choose to eat an average of 11% saltbush in the diet when they have access to green legumes in spring. Perhaps the animals have developed a taste for salt or another secondary compound in the saltbush. This may have implications for the high productivity saltland grazing systems that are emerging from MIDAS models. In these systems, the understorey in saltland pastures should be grazed in spring and the saltbush is grazed in autumn. This may not be possible if the sheep eat the saltbush in spring.

We found that the *in vitro* DOMD of saltbush does not vary during the year however protein levels may vary. Presumably the jump in the protein levels that were observed in spring 2005 is a combined result of fertiliser application and fixation of nitrogen by the legumes in the understorey. The reported *in vivo* organic matter digestibility of saltbush forage grown without irrigation in Australia ranges from 30 to 66%, with many studies demonstrating that saltbush has energy values below maintenance for mature, dry sheep. The old man saltbush in this study maintained *in vitro* DOMD values of between 48 and 52%. These values are overestimates however as laboratory prediction of digestibility requires calibration with standards of known *in vivo* digestibility. There are currently no *in vivo* standards that are from halophytic plants but several recent animal house studies indicate that in vivo DOMD of saltbush is lower than 50%..

Both saltbush species accumulated between 25 to 35% salt in the EDM. This is consistent with previous findings of salt accumulation in the leaves of halophytes ranging from 15 to 27% (Warren *et al.* 1990, Norman *et al.* 2004). These levels of salt depress both feed intake and digestibility of the feed (Masters *et al.* 2005). Sheep will stop eating salty forage after they have ingested approximately 200g salt/day (Masters *et al.* 2005). This means that if the 'edible' component of a saltbush shrub has 25% ash in the dry matter and has an *in vivo* organic matter digestibility of 50%, a 50kg mature wether will stop eating after ingesting about 800g of biomass, 250 g short of the 1050g of predicted biomass required to maintain liveweight (Masters *et al.* 2005, Freer *et al.* 1997). In early winter, the understorey sward did accumulate some high levels of salt; this will contribute to a decline in the ability of the animals to eat more than 800g of saltbush per day.

In this study, we estimated growth rates of mature saltbushes subject to regular grazing for the first time. Saltbush growth rates are slow and biomass production is poor. The growth rate of old man saltbush EDM ranged from 0.38 to 4 kg/ha.day (or 0.59 to 5.57 g EDM/day per individual shrub). The wavy-leaf saltbush was even less productive, growing from 0.01 to 0.46 kg/ha.day of EDM (0.01 to 0.64 g/shrub.day). The peak biomass growth times ware in autumn and early winter. Figure 10 models saltbush productivity at various planting densities using these rates of saltbush growth. This model assumes that there are not competitive interactions between the saltbushes at the higher densities. A planting density of 1000 stems/ha is required to provide 1000 kg of biomass per year per hectare.

Acknowledgements

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Growth of *Atriplex nummularia* (old man saltbush) in a novel circular 'wheel' experiment on four saline sites in the WA wheatbelt. 1. Site characterisation, saltbush growth, interplant competition, mineral nutrition and soil texture

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Introduction

This paper is part of a larger investigation (see also paper 2 – Barrett-Lennard and Altman 2007), to examine the effects of site condition and plant spacing on saltbush growth and water use. The trials (at four sites) have been conducted in a novel design in which rows of old man saltbush (*Atriplex nummularia*) were planted at 30^{o} angles to converge like the spokes of a wheel at a common centre.

A. nummularia has a dimorphic or dioecious reproductive system. This creates wide genetic variation within populations, and can make comparisons between sites difficult. In the present work, all sites were sown with a single clone of *A. nummularia*. Therefore, the differences between sites can therefore be ascribed more specifically to environment rathe than genotype.

In this experiment our principle focus has been on the effects of site, spacing and plant nutrition on production.

Materials and Methods

Layout of trials

The 'Wheel' experiments were planted at four sites near: Wubin (property of Keith Carter), Meckering (property of Colin Pearce), Yealering (property of Chris Walton) and Pingaring (property of Michael Lloyd). At each site, a commercial clone ('Eyres Green') of *Atriplex nummularia* (gift of the Topline Plant Company in South Australia) was planted in the spring of 2003[1], in rows intersecting each other (like the spokes of a wheel) at 30 degree angles.

Each site was cultivated using available farm machinery. On each site, the rows were ripped or deep cultivated to promote early root growth. Seedlings were planted by hand 2 m apart within rows, and rows were 75 m long.

Plant locations within the 'wheels' are identified from row number and plant number (within rows) from the centre of the wheels. In August 2005 and again in July 2006, fertiliser ('NPK Blue') was applied to plants at locations 8 to 35 on half of the rows (Rows 1, 2, 5, 6,

[1] Dates of planting of the Wheel experiments were:
- Wubin – 11 August 2003
- Pingaring – 18 August 2003
- Yealering – 29 August 2003
- Meckering – 5 September 2003

9 and 10) at each site.[2] The fertiliser was applied at the rate of 0.4 kg per plant which would have supplied each plant with 48 g N, 21 g P and 56 g K per plant per application.

An important part of the trial has been to examine the effects of the plants on water use. Monthly measurements were made of the effects of plants at 0, 3, 6 and 12 m distance from the rows of saltbushes on stored soil moisture (measured using a neutron moisture meter – Campbell Pacific Nuclear Corp.) and groundwater levels (measured with 3 m deep piezometers). Every 6 months, the piezometers were pumped out, new groundwater was allowed to seep in, and samples of groundwater were collected for measurement of electrical conductivity and pH.

Use of neutron moisture meter to estimate air filled porosity in the field

At each wheel experiment, simultaneous measurements were made of water-table depth (using a tape measure in a shallow piezometer) and soil moisture down the soil profile using a neutron moisture meter in an adjacent (2 m distant) access hole. We were therefore able to relate changes in soil moisture to changes in the depth of the water-table. At two of our sites (Meckering and Yealering), water-tables rose to within 30 cm of the soil surface in June/July 2005. The neutron readings at these times therefore provided us with a log of neutron counts associated with virtual soil saturation. At other times, neutron counts less than this maximum occurred because water-tables were deeper. We calculated the difference in neutron counts between the counts at saturation (in June/July 2005) and the counts at other times, and related this difference to water-table depth. The difference in neutron counts was converted to an air-filled porosity, assuming that 100% volumetric water content was equivalent to 19,850 counts on our neutron moisture meter (determined by measuring counts in a 200 L drum filled with water of similar groundwater salinity).

Measurement of canopy volume

Measurements were made at monthly intervals of plant canopy diameter and height in 12 regularly measured plants (plants 2, 3, 4, 5, 6, 8, 10, 15, 20, 25, 30 and 35) in each row. Shoot canopy volume was calculated assuming that canopies were hemispheroid in shape. For most shrubs, volume was calculated as $1/6\ \pi * D_1 * D_2 * Ht$, where D_1 is the widest diameter of the canopy, D_2 is the canopy diameter perpendicular to D_1, and Ht is the height of the canopy. At the Meckering site, after September 2005, the shrub canopies became so inter-grown that two canopy diameters could no longer be measured. Canopy volume was therefore calculated as $1/6\ \pi * D * D * Ht$, where D is the diameter of the canopy perpendicular to the direction of the row, and Ht is the height of the canopy.

Two ratios were calculated to illustrate the effects of plant spacing and fertiliser on canopy growth:

(a) Ratio of volumes of 'inner' to 'outer' plants. Using data from non-fertilised rows, this was the ratio of geometric mean volume of plants 2, 3, 4, 5 and 6 (the 'inner' plants in each row) to the geometric mean volume of plants 15, 20, 25, 30 and 35 (the 'outer' plants in each row).

[2] The initial application of fertiliser was made on 2 August 2005 (Wubin) 15 August 2005 (Meckering and Yealering), and 16 August 2005 (Pingaring). The second application of fertiliser was made on 17 July 2006 (Wubin), 18 July 2006 (Meckering), 19 July 2006 (Yealering) and 20 July 2006 (Pingaring).

(b) Ratio of volumes of non-fertilised to fertilised plants. Using data from 15, 20, 25, 30 and 35 (the 'outer' plants in each row), this was the ratio of geometric mean volume of plants from fertilised rows (rows 1, 2, 5, 6, 9 and 10) to non-fertilised rows (rows 3, 4, 7, 8, 11 and 12).

Destructive harvests

Destructive harvests of 'grazable biomass' of selected plants were undertaken in May or June 2006. Leaves and twigs were hand stripped and weighed fresh in the field using a pan balance. The harvested material was then sub-sampled and dried in a fan forced oven at 40°C. Oven dried material was separated into leaves and twigs, and the weight of the leaf fraction was used to estimate total leaf weight for the whole harvested plant. Samples of dried leaf were analysed for animal nutritive value using the CSIRO feed testing laboratory.

Analysis of nutritive value for animals

Composite samples were constructed using the leaves hand harvested in May/June 2006. The composites consisted of equal amounts by leaf weight of 2 to 6 plants and the different leaf samples were composed as follows:

- 'Inner nil-1' – plants from locations 2, 3 or 4 in non-fertilised rows.
- 'Inner nil-2' – plants from the unfertilised locations 2, 3 or 4 in fertilised rows.
- 'Mid nil' – plants from locations 5 to 20 in non-fertilised rows.
- 'Mid fert' – plants from locations 5 to 20 in fertilised rows.
- 'Outer nil' – plants from locations 20 to 35 in non-fertilised rows.
- 'Outer fert' – plants from locations 20 to 35 in fertilised rows.

Analyses for Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF), Organic Matter and Nitrogen were determined on composite samples by the CSIRO Feed testing Laboratory using the NIR method. The analysis was part of a larger data set of seven species (old man saltbush, river saltbush, small leaf bluebush, samphire, rhodes grass, salt water couch and lucerne). Linear correlations between NIR and wet chemistry analyses (n = 21) had r^2 values of 0.90 for NDF, 0.85 for ADF, 0.77 for organic matter (or 0.91 with the elimination of a single point for samphire) and 0.82 for nitrogen (or 0.90 with the elimination of a single point for samphire). All correlations were significant at $P <$ 0.001.[3]

Sampling for nutritive value

There has been general consensus that macronutrient concentrations in crops should be measured in 'fully expanded leaves'. However, it was not clear for saltbush when leaves became 'fully expanded'. To clarify this issue, in September 2005, 30 cm branches were harvested, and detailed measurements were made on the leaves of the main stem and

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[3] Lines of best fit were:
$ADF_{WET} = 1.1158*ADF_{NIR} – 3.3884$
$NDF_{WET} = 1.0685*NDF_{NIR} – 4.5407$
Organic matter without the anomalous samphire point. $OM_{WET} = 1.0037*OM_{NIR} + 0.2139$
Nitrogen without the anomalous samphire point. $N_{WET} = 0.855 * N_{NIR} +0.3193$

their position on the branch. The maximum width of each leaf was measured at right angles to the leaf midrib using a ruler. These widths were related to the location of the leaf in terms of its distance from the branch apex. The length of each internode along the stem was also measured with a ruler.

Plants were sampled for mineral nutrient composition in September 2005 and September 2006 (data not reported). Ten centimetre long apical shoot segments were sampled from three plants in each row. These were pooled into three composite samples per fertiliser treatment per site and stored in an esky. Back in the laboratory, the sampled twigs were cut into two segments, from the shoot apex to 5 cm, and from 5 to 10 cm. These segments were then further divided into leaves of the main stem, axillary buds and axillary leaves, and stems. The material was then dried in a fan-forced oven at 40°C, ground, and analysed for N, P and K by the WA Chemistry Centre.

Analysis of N by the mass spectrometer

Apical shoot segments (~4.5 cm long) were collected in the field and dried in a fan-forced oven at 40°C. These were pooled into composite samples (by distance from the centre of the wheel) and ground. They were then analysed for N in a mass spectrometer.

Results

1. Site characteristics

Extensive soil sampling has been conducted over the four sites, but most of this data is still being analysed at the WA Chemistry Centre. We present here data on soil characteristics associated with the growth of large and small plants on the site (Figure 1), and data on the estimated air filled porosity of the soils at Meckering and Yealering (Figure 2).

<u>“Large” and “small” plants</u>

In July 2005 we measured plant canopy volumes, identified the three largest and three smallest plants per site, and took composite soil (0–25 cm depth) and leaf samples from the locations of these plants. The samples were collected from the outer “measured plants” in each row (plants 15, 20, 25, 30 or 35) to minimise the chance that plant size was affected by the interplant competition in the inner areas of the wheel. The differences in canopy volume are reported in Figure 1, and the soil and plant data associated with these differences are reported in Tables 1 and 2 below.

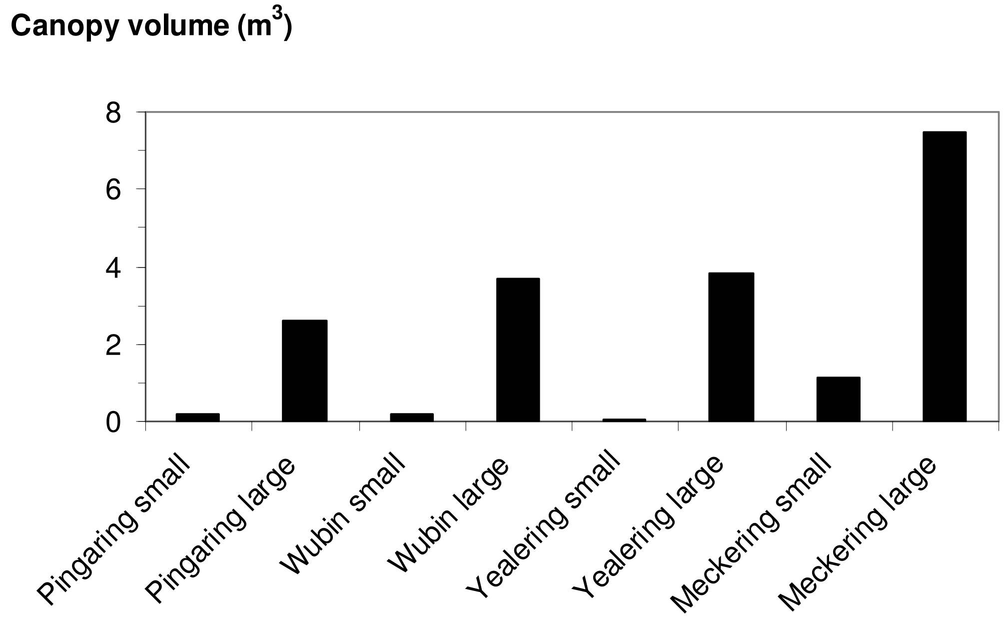


Figure 1. Differences in average canopy volume between the three largest and three smallest plants per site.

Table 1. Soil characteristics associated with large and small plants. Data are composite samples of soil near the three largest or three smallest plants per site (July 2005).

A. Mechanical analysis, exchangeable cations and exchangeable sodium percentage

Site, sample	Sand	Silt	Clay	CEC NH_4Cl	Ca (exch)	Mg (exch)	Na (exch)	K (exch)	ESP
	%	%	%	me%	me%	me%	me%	me%	%
Meckering small	95.5	2.5	2	1	0.98	0.14	0.10	0.05	10
Meckering large	95.5	2.5	2	1	0.74	0.22	0.34	0.05	34
Pingaring small	67	8.5	24.5	9	1.64	3.07	2.75	0.54	31
Pingaring large	59	7	34	12	1.90	4.41	4.16	0.87	35
Yealering small	59.5	11.5	29	15	3.39	7.21	2.67	0.45	18
Yealering large	71.5	10.5	18	9	1.47	3.88	2.07	0.26	23
Wubin small	85.5	4.5	10	4	2.56	1.20	0.63	0.33	16
Wubin large	85	4.5	10.5	4	2.31	1.30	0.63	0.34	16

B. Properties of the saturation extract, exchangeable sodium percentage, boron, chloride and nitrogen

Site, sample	Sat %	EC_e	pH_e (SE)	HCO_3 (SE)	CO_3 (SE)	B $CaCl_2$	Cl	N (total)	Org C (W/B)
	%dsb	mS/m		me/L	me/L	mg/kg	mg/kg	%	%
Meckering small	22	59	7.1	1.2	<0.1	0.4	30	0.026	0.32
Meckering large	18.6	160	7.5	1.6	<0.1	0.5	97	0.022	0.26
Pingaring small	32.6	490	8.2	3.7	<0.1	4.4	440	0.028	0.35
Pingaring large	38.8	710	8.4	4.3	<0.1	6.6	520	0.032	0.38
Yealering small	42.6	460	8.2	NSS	NSS	3.5	190	0.044	0.58
Yealering large	29.3	260	8.1	NSS	NSS	2.8	160	0.030	0.41
Wubin small	18.2	850	7.4	2.3	<0.1	1.9	420	0.024	0.35
Wubin large	17.8	1600	6.8	0.5	<0.1	1.4	1000	0.032	0.43

Table 2. Plant mineral nutrient characteristics associated with large and small plants. Data are composite samples of leaves from the three largest or three smallest plants per site (July 2005).

A. Macronutrients and salts (% dry wt).

Site/sample	N	P	K	Ca	Mg	S	Na	Cl
Meckering small	2.08	0.29	3.11	0.93	0.66	0.47	4.69	5.54
Meckering large	1.88	0.30	4.14	0.93	0.72	0.54	4.77	5.72
Pingaring small	2.14	0.18	3.67	1.34	0.82	0.55	5.96	7.62
Pingaring large	2.52	0.24	3.52	1.25	0.71	0.63	6.11	8.8
Wubin small	2.11	0.25	5.26	1.23	0.84	0.50	5.36	8.56
Wubin large	2.64	0.26	4.37	0.96	0.61	0.51	5.44	8.44
Yealering small	1.53	0.17	3.32	1.34	1.22	0.47	5.12	6.67
Yealering large	1.86	0.34	3.25	0.6	0.65	0.49	4.58	5.63

B. Micronutrients (mg/kg dry wt)

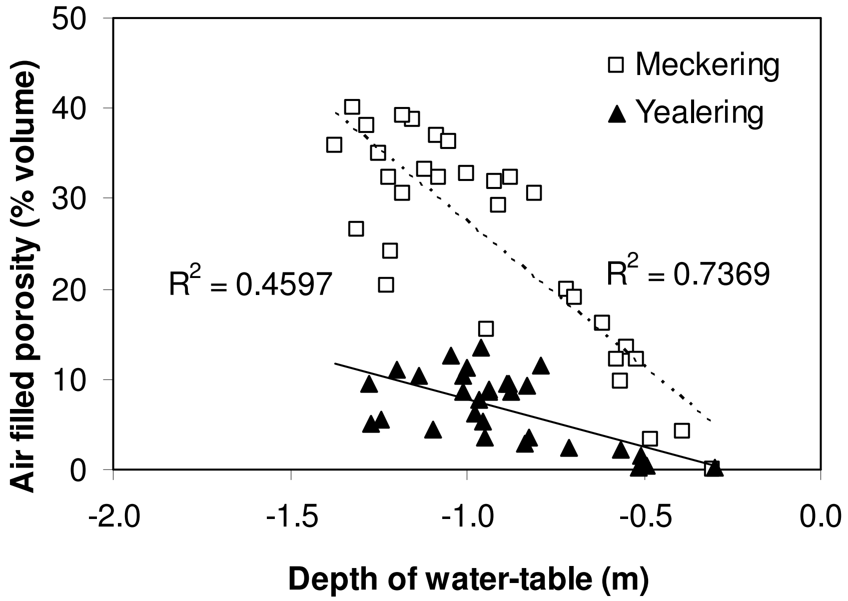
Site/sample	B	Cu	Fe	Mn	Mo	Zn
Meckering small	39	8.4	58	250	<2	55
Meckering large	45	9.6	57	220	2	62
Pingaring small	52	22	59	260	<2	38
Pingaring large	45	20	55	160	<2	31
Wubin small	38	18	73	670	<2	63
Wubin large	36	18	67	520	<2	47
Yealering small	64	11	62	250	<2	52
Yealering large	54	9.9	73	180	<2	49

Estimated air filled porosity at Meckering and Yealering

One of the perplexing issues facing us in this trial was the cause of the difference in growth between the plants at Meckering and at Yealering. Both sites had similar depth to water-table and salinity of the groundwater, but there was a profound difference in growth between the two sites. One clue about the cause of this difference was to be found in the soil texture data – sandy clay loam (29% clay) in the upper profile at Yealering, but sand (2% clay) in the upper profile at Meckering (Table 1).

Using the neutron moisture meter data, we determined the effects of differences in depth to the water-table on the air-filled porosity of the soil profile. Although there was a significant effect of water-table depth on the air-filled porosity at both sites, this relationship was profoundly different between the Meckering and Yealering sites (Figure 2). At 30 cm depth, the line of best fit for Yealering had only a third of the slope of the relationship for Meckering. Furthermore we estimate that the air-filled porosity was greater than 10% for ~85% of the time at Meckering, but only ~20% of the time at Yealering (Figure 2a). This difference has profound implications for root growth and function. In reviewing the literature on soil physical conditions and drainage, Wesseling and van Wijk (1957) concluded that "as a first approximation, one may assume that 10% of volume of airfilled pores is the lowest value at which air can be exchanged in the soil". Thus at Yealering roots at 30 cm depth were hypoxic (O_2 deficient) most of the time, whereas at Meckering this was generally not the case. At 50 cm depth, the air-filled porosity at both sites was consistently less than 10% (Figure 2b).

(a) 30 cm depth



(b) 50 cm depth

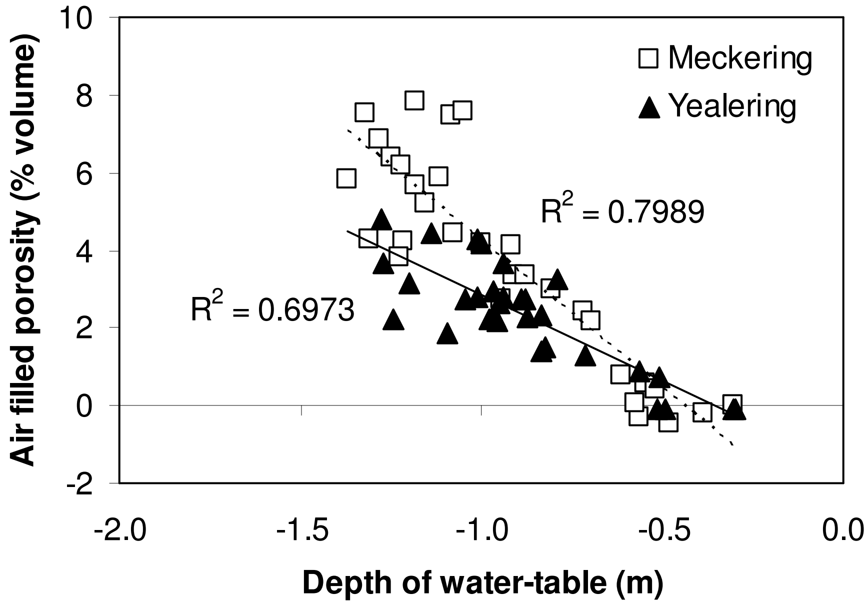


Figure 2. Relationship between depth to water-table and estimated air-filled porosity at (a) 30 cm depth, and (b) 50 cm depth in the soil profile.

Canopy volume

The growth of this saltbush clone was strongly affected by conditions at the four sites (Figure 3). Canopy volumes expanded faster with time at Meckering than at any other site, and by the end of the experiment volumes at Meckering were about twice those at Wubin and Pingaring, and these were about twice those at Yealering.

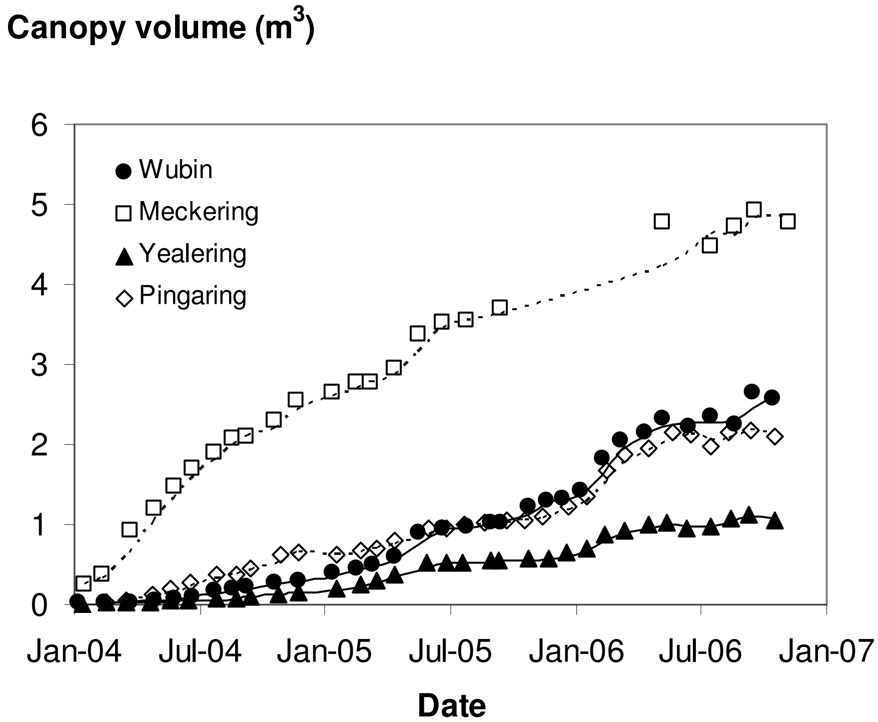


Figure 3. Change in geometric mean canopy volume with time. Each point is the geometric mean of 144 plants. Lines of best fit are two period moving averages.

Calculations of the ratio of the volume of 'inner' to 'outer' plants showed that initially plants grew faster at the centre of the wheels (Figure 4). We attribute this to better root growth associated with the intersecting of the rows of deep ripping at planting at the centre of the wheels (cf. Barrett-Lennard 1993). However, by the conclusion of the trial, the ratio of volume of 'inner' to 'outer' plants had decreased to values less than 1 at three sites, indicating that competition between plants was more limiting to plant growth at the centre than the periphery of the wheels. By the end of the trial, this competition was clearly acute at Pingaring, Yealering and Meckering (ratios of 0.5, 0.6 and 0.7 respectively – Figure 4).

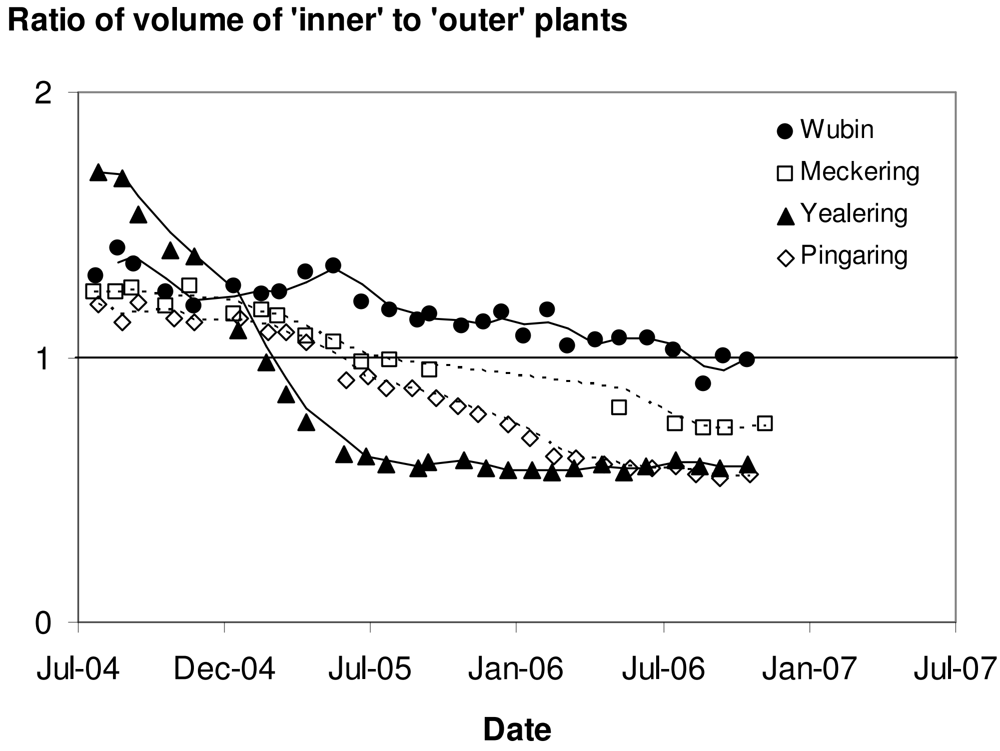
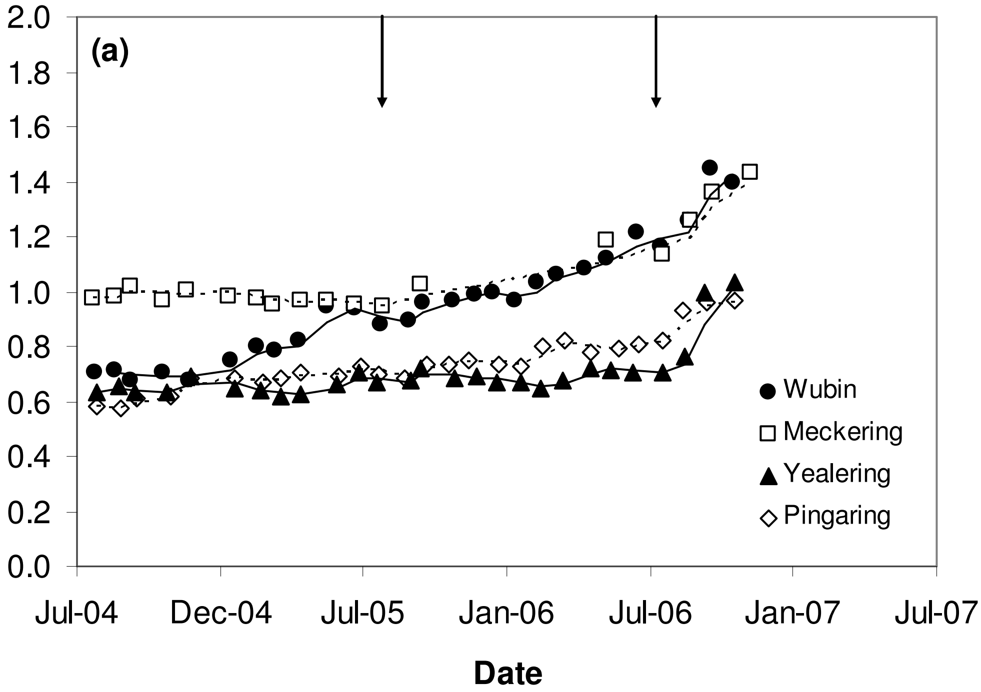


Figure 4. Change with time in ratio of geometric mean volume of ‘inner’ to ‘outer’ plants. Lines of best fit are two period moving averages.

Calculations of the ratio of volume of fertilised to non-fertilised plants showed that application of fertiliser increased the plant growth at all sites. Clearly plant growth at all sites was limited by at least one of the applied nutrients. By the conclusion of the trial, the time trend in this ratio had increased in slope at all sites (Figure 5a). Although the density of points in the early months of 2006 is poor for Meckering, extrapolation of trend lines suggest that this increase occurred first at Meckering (around the end of January 2006, Figure 5b). At the other sites the change in time trend appeared to be ~6 months later.

Ratio of volume of fertilised to non-fertilised plants



Ratio of volume of fertilised to non-fertilised plants

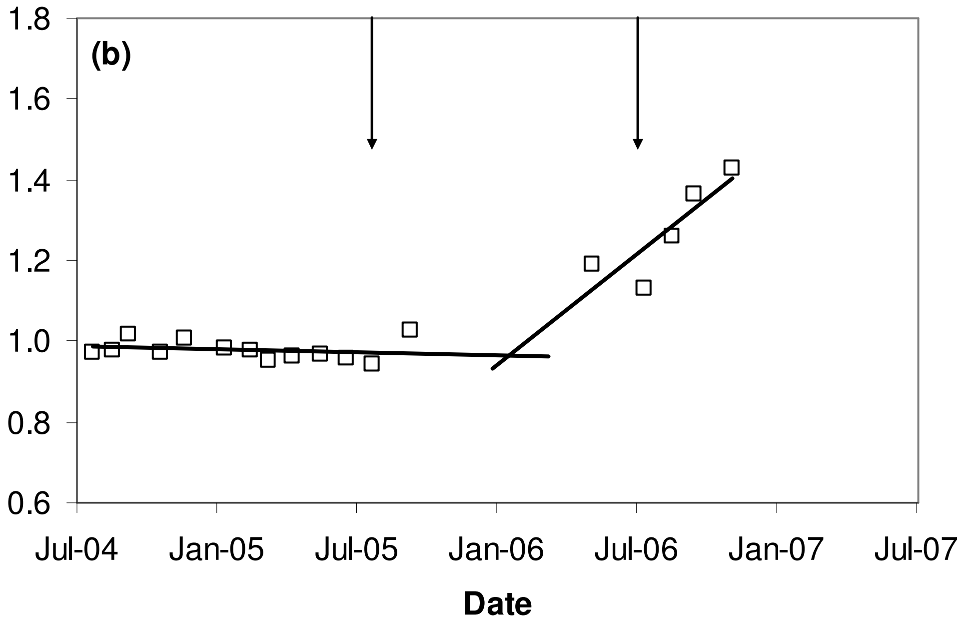


Figure 5. Change with time in ratio of volume of fertilised to non-fertilised plants: (a) all sites, (b) Meckering site with lines of extrapolation to time of change of slope (20 January 2006). Dates of fertiliser application are indicated by the arrows. Lines of best fit in (a) are two period moving averages.

Destructive harvests – relationship between plant volume and leaf production

Irrespective of position in the wheel and level of fertiliser application, there was a strong relationship between canopy volume and the biomass of leaves harvested in May/June 2006 (Figure 6). Lines of best fit through the origin were all significant ($P < 0.001$) and had r^2 values between 0.95 and 0.68. At three of the sites (Pingaring, Wubin and Yealering), the slopes of the lines of best fit were similar (0.18–0.23 kg dry leaf per m^3 of volume). However, at Meckering the slope was far lower (0.11 kg leaf per m^3) than at the other three sites.

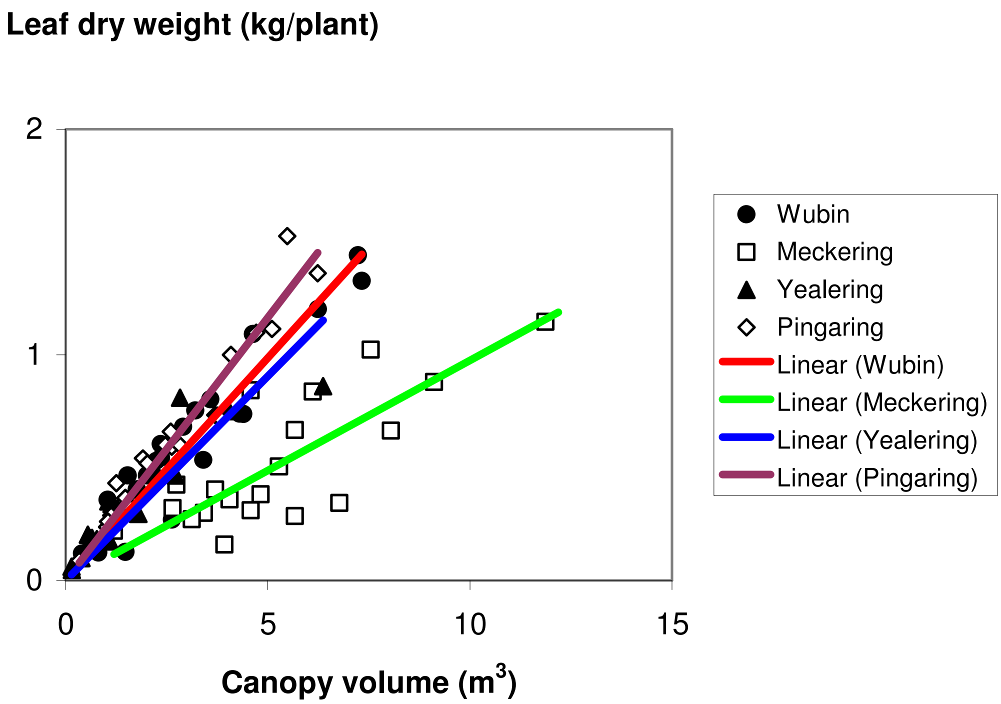


Figure 6. Relationship between canopy volume and harvested leaf biomass at the four sites. The points making up these lines were sampled from throughout the wheels (positions 2 to 35) and had either fertiliser or no fertiliser treatment.

We examined the effect of distance from the centre of the wheel on the ratio of leaf weight to canopy volume. At Meckering there was a significant ($P < 0.01$) power relationship between this ratio and distance from the centre of the wheel (Figure 7). However, there was no significant effect of distance from the centre of the wheel on this ratio at any other site. This result is also consistent with the view that leaf production of the plants at Meckering was impacted by increased competition towards the centre of the wheel.

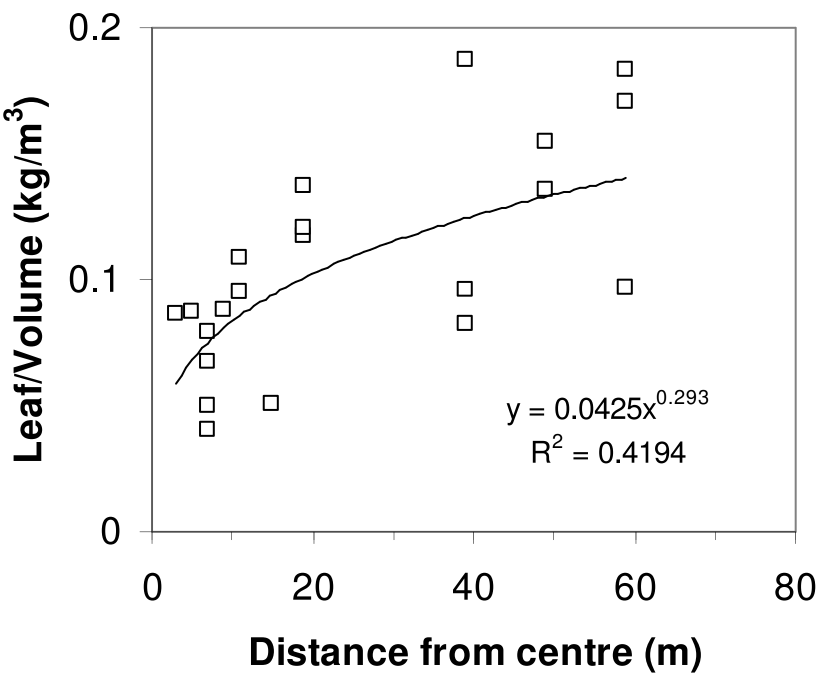
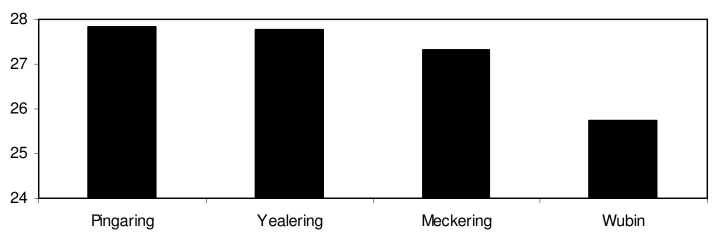


Figure 7. Relationship between ratio leaf/canopy volume and distance from the centre of the wheel at Meckering. The line of best fit is significant at $P < 0.01$.

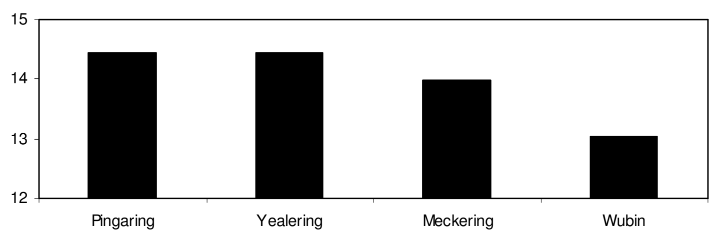
Analysis of nutritive value for animals

We have graphed the results from the analysis of the composite samples harvested in May/June 2006 in two ways: (a) as the averages for each site (Figure 8), and (b) as the averages for each location/fertiliser treatment (Figure 9).

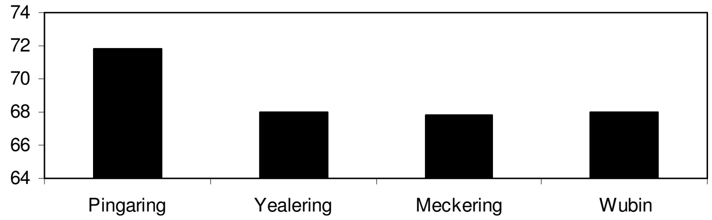
(a) NDF (% dry wt)



(b) ADF (% dry wt)



(c) Organic matter (% dry wt)



(d) Nitrogen (% dry wt)

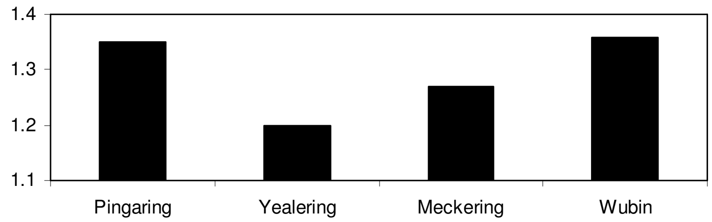
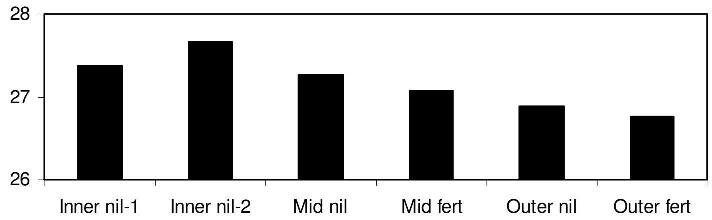
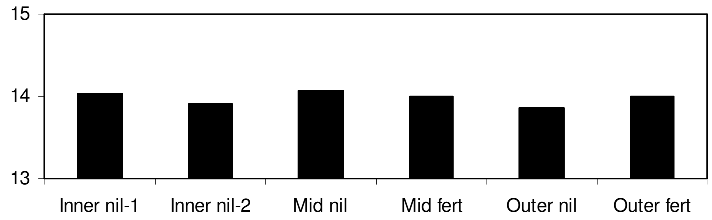


Figure 8. Nutritive value characteristics of 'Eyres Green' clones of *A. nummularia* grouped by site. Plants were bulk sampled in May/June 2006 and analysed by the NIR method. Values are the averages of 6 composite samples per site of: (a) NDF, (b) ADF, (c) Organic Matter, and (d) Nitrogen.

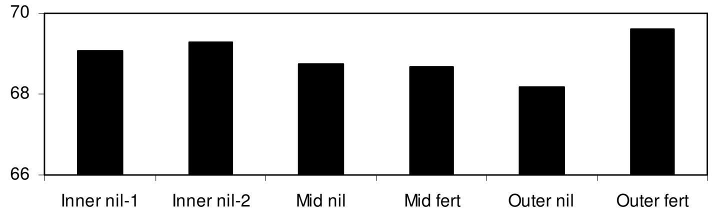
(a) NDF (% dry wt)



(b) ADF (% dry wt)



(c) Organic matter (% dry wt)



(d) Nitrogen (% dry wt)

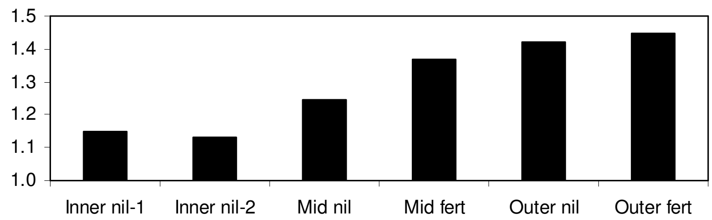


Figure 9. Nutritive value characteristics of the 'Eyres Green' clone of *A. nummularia* grouped by location and fertiliser treatment of composite sample. Plants were bulk sampled in May/June 2006 and analysed by the NIR method. Values are the average of values from four sites of: (a) NDF, (b) ADF, (c) Organic Matter, and (d) Nitrogen.

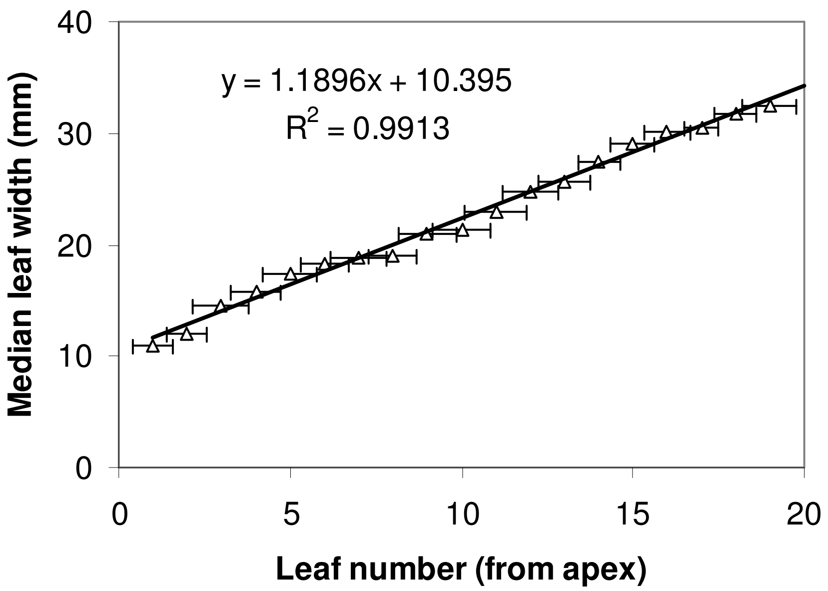
Average NDF and ADF concentrations in the leaves as determined by the NIR method were quite low (Figures 8 and 9). It is useful to compare these data with those in the unpublished database of Warren and Casson. In their analysis of 82 *Atriplex* species sampled in autumn, NDF and ADF values at the lowest decile were 28.8 and 14.6% respectively. The values of ADF and NDF in the saltbushes of the wheel experiments were all lower than these values (Figures 8 and 9).

Nitrogen concentrations were lower at the two sites subject to waterlogging, Yealering (1.2% dry wt) and Meckering (1.3% dry wt), than at Pingaring and Wubin (both 1.4% dry wt). They were also affected by proximity to the centre of the wheel, with concentrations being around 1.1% at the centre and more than 1.4% at the periphery of the wheels. All of these values seem low compared to those measured in other investigations. The Warren and Casson database lists N analyses for 96 *Atriplex* genotypes, and the concentrations associated with the first and second deciles in this database were 1.3% 1.6% respectively.

Mineral nutrient concentrations

Analyses to determine macronutrient deficiencies in plants are widely conducted on the youngest fully expanded leaves (Reuter *et al*. 1997). What would be the equivalent tissues to this in saltbush? Thirty centimeter long branches were sampled to determine the maximum width of leaves and length of the internode between leaves. It was found that average leaf width was correlated with leaf number from the apex (Figure 10a). Leaves continued to increase in width (and hence size) until they were shed. Stems continued to expand until about the eighth internode, about 60 mm from the apex (Figure 10b)

(a)



(b)

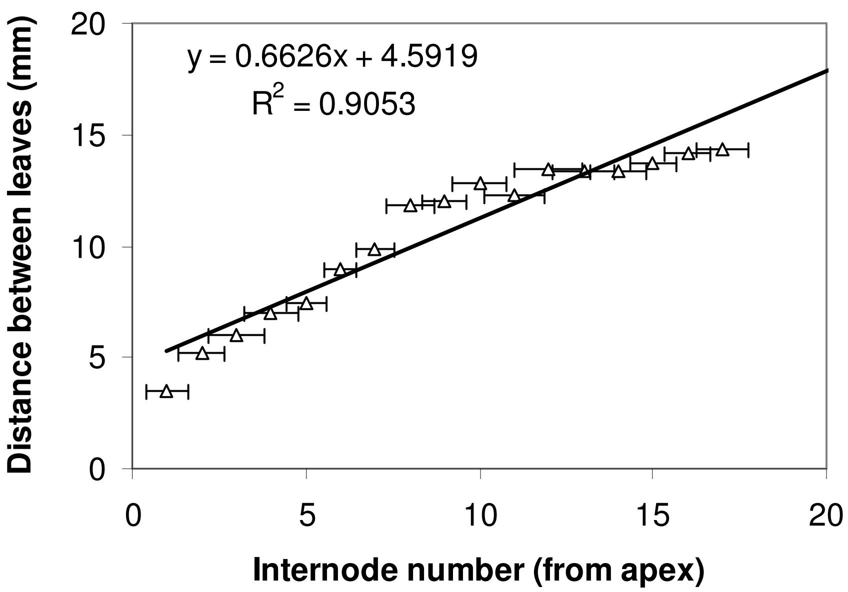


Figure 10. Identification of growing leaves and stems: (a) relationship between leaf width and leaf number from the apex, and (b) relationship between distance between leaves and internode number from the apex. Each point is the mean ± SEM of 19-43 samples sampled in September 2005. Although 48 branches were sampled (6 branches per fertiliser treatment, 2 fertiliser treatments per site, 4 sites), leaves were not included in the analysis if they had been attacked by insects.

In the absence of any clear indications to the contrary, we decided to sample apical (0-10 cm long) saltbush stem segments that included leaves, stems and axilliary buds, and express concentrations on the basis of the percentage dry weight of the total segment. The effect of fertiliser application on the concentration of N, P and K in this segment is shown in Figure 11.

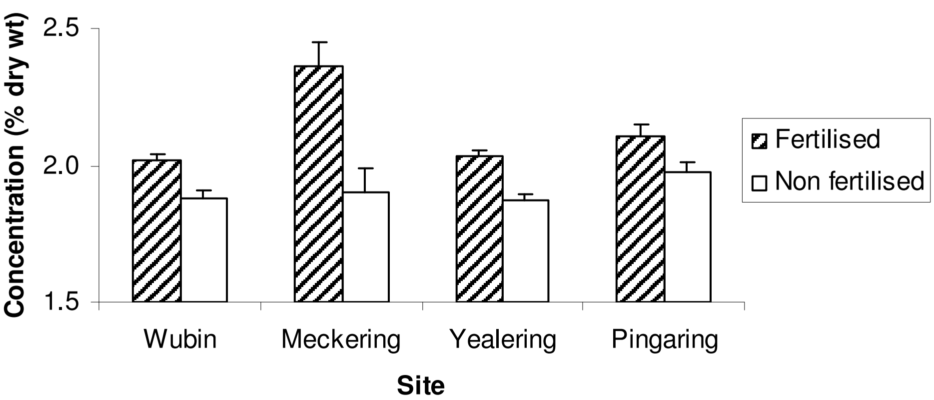
Nitrogen. Non fertilised plants had N concentrations of 1.9 to 2.0% dry weight at all sites. Application of fertiliser increased concentrations by 24% at Meckering, but only by 7–8% at the other three sites (Figure 11a).

Phosphorus. In non-fertilised plants, P concentrations were lower (0.22–0.24% dry weight) at Wubin and Pingaring than at Meckering and Yealering (both 0.31% dry weight). Application of fertiliser increased concentrations in the leaves by 7, 11 and 20% at Pingaring, Wubin and Meckering respectively. Fertiliser had no effect on the P concentrations in the shoot segments from Yealering (Figure 11b).

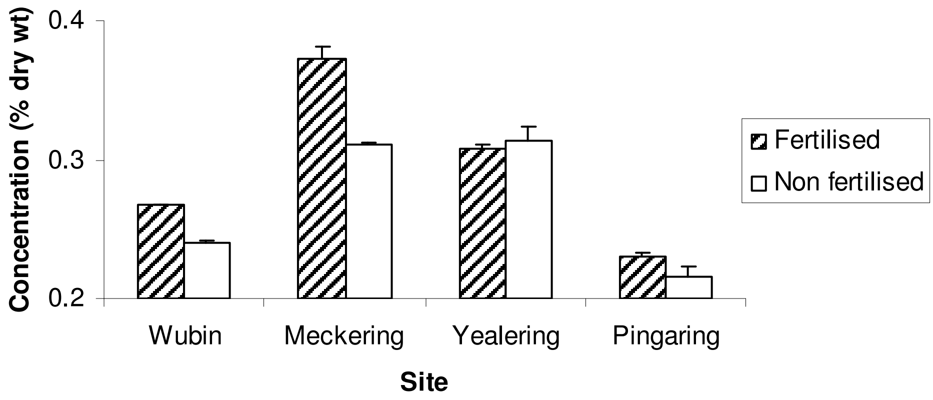
Potassium. In non-fertilised plants, the lowest K concentration was at Yealering (2.7% dry weight). Concentrations at the other three sites were in the range 3.6–4.4% dry weight. Applications of fertiliser had negligible effects on shoot concentrations (-6 to +3% change).

So which nutrient was mainly responsible for the increase in growth, first at Meckering and subsequently at the other three sites (cf. Figure 5a,b)? The nutrient most consistent with our data is nitrogen. Nitrogen was the only supplied macro-nutrient that was present at low concentrations in the tissues of plants at Meckering, and it was the macro-nutrient that showed most rapid increase in concentration in the shoots at Meckering after fertiliser application (Figure 11a).

(a) Nitrogen



(b) Phosphorus



(c) Potassium

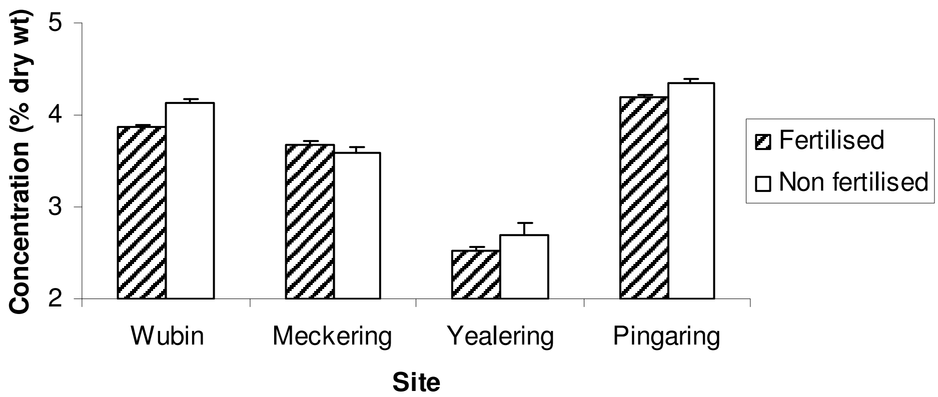
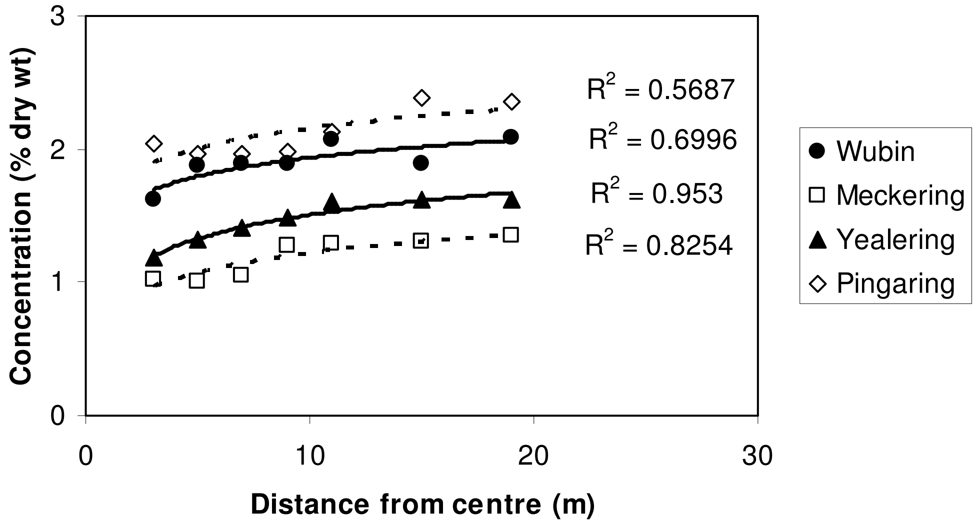


Figure 11. Effects of fertiliser application on mineral nutrient concentrations in apical 10 cm segments of saltbush shoot. Fertiliser was applied in August 2005, and samples were taken 5–7 weeks later. Values are the means of three replicates. Bars are the SEM.

Data collected using a mass spectrometer showed that the concentration of N in shoot segments was affected by site, season and distance from the centre of the wheels (Figure 12). In January 2005, average N concentrations in apical shoot segments were lowest at Meckering and Yealering (1.2 and 1.5% dry weight respectively) and higher at Wubin and Pingaring (1.9 and 2.1% dry weight respectively) (Figure 12a). By July 2005, foliar N concentrations had increased at all sites, but were still lower at Yealering (1.9% dry weight) than at Meckering, Pingaring and Wubin (2.3, 2.4 and 2.6% respectively) (Figure 12b). With one exception, at all sites and times, the concentration of N decreased with proximity to the center of the wheel; except for Pingaring in July 2005, logarithmic relationships between distance from the centre of the wheel and the concentration of N in the shoot segments were significant at $P < 0.05$. Three relationships (Meckering at both January and July 2005, and Yealering in January 2005) were significant at $P < 0.01$.

(a) January 2005



(b) July 2005

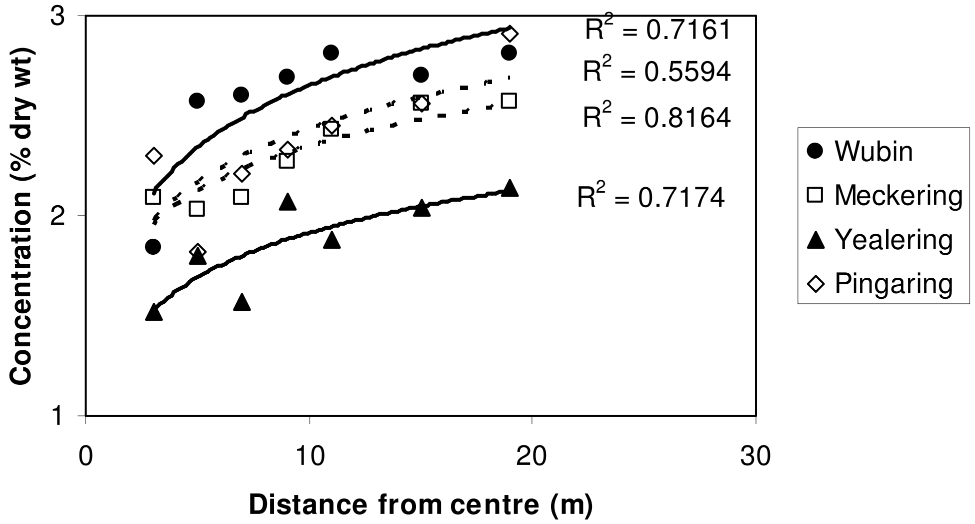


Figure 12. Effects of site, season and distance from the centre of the wheel on the concentration of N in apical segments. (a) January 2005, (b) July 2005. Each point is the mean of two readings from a composite of 12 samples.

Discussion

Spacing. It has been known for a number of years that plant spacing affects the size to which saltbushes will grow. Malcolm *et al*. (1988) grew five *Atriplex* species on a site near Kellerberrin in WA at spacings of 1x1, 1x2, 2x2, 2x3 and 3x3 m. After 20 months growth there were highly significant differences in the grazable biomass between the five species at the wider but not the narrower spacings. The largest growing species (*Atriplex amnicola*) had similar productivity on an areal basis (~1.6 kg/ha) when sown at spacings of 1x2, 2x2, 2x3 or 3x3 m. In a subsequent trial at Esperance, Barrett-Lennard (1991) showed that the effects of interplant competition were apparent at even wider plant spacings. After 21 months growth in blocks at different spacings, there were 20 and 50% increases in plant size in *Atriplex amnicola* and *A. cinerea* as spacings increased from 6.3 x 6.3 m to 8.9 x 8.9 m. It is clear that in both these experiments, plants were competing for some limiting resource even at quite wide spacings. What is the limiting resource? When we commenced these trials we thought that the factor most limiting saltbush growth was likely to be water. However, the availability of soil macro-nutrients like nitrogen is another distinct possibility.

Nitrogen. There is little information on the concentrations of nitrogen that occur in saltland soils. Waterlogging causes soils to become nitrogen deficient through the process of 'denitrification'; that is in the absence of oxygen, the activity of anaerobic bacteria in the soil causes the successive reduction of nitrate to nitrite, nitrite to nitrous oxide, and nitrous oxide to nitrogen gas ( ). Although saltland is subject to waterlogging, remarkably the process of denitrification on saltland has not been previously been studied.

In the present trials, the water-tables were shallower at Yealering and Meckering (median depths of 0.9 and 1.0 m respectively) than at Wubin and Pingaring (median depths of 1.8 and 2.0 m respectively) (reported in Barrett-Lennard and Altman 2007). The concentration of N in leaf samples (collected in July 2005, or May/June 2006) and apical segments (collected in January 2005 and July 2005) were always lower at the sites with the shallower water-tables (Yealering and Meckering) than at the sites with deeper water-tables (Wubin and Pingaring) (Table 2A; Figures 8, 11a and 12). This paper makes a case that shallow water-tables caused greater hypoxia at Yealering than Meckering (Figure 2). It is therefore not surprising that concentrations of N in leaves were often lower at Yealering than Meckering (eg. Table 2a; Figures 8 and 12b).

At Meckering the plants had a far lower ratio of leaves to canopy volume than at the other sites (Figure 6), and this ratio was related to plant spacing (distance from the centre of the wheel) (Figure 7). As noted in the Results, we believe that this decreased leaf production has been caused by nitrogen deficiency, but we a currently conducting a further small trial to confirm this.

Variation in nitrogen in the leaves – implications for animal nutrition. One of the striking features of our work has been the wide range of N concentrations measured – between sites, between small and large plants, between bulk samples and apical segments, and between seasons (Table 2A and Figures 7, 11a and 12). This wide range of variation clearly has implications for livestock nutrition. Animals that graze shoot tips may enjoy a higher plane of nutrition than those forced to graze bulk leaves. Animals that graze saltbushes in winter may have a higher plane of nutrition than those that graze saltbushes in summer.

Atiq-ur-Rehman (1995) examined the effects of season and distance down the stem on the concentration of N in the tissues of *A. amnicola* growing on saline land near Katanning WA. Between 20 April and 1 June 1994, the concentration of N in leaves of ungrazed plants 10 cm from the branch apex increased from 1.7 to 3.0% dry weight. In this study, sheep clearly sought out the feed with higher concentrations of N. Left ungrazed, leaf/stem segments 10 cm from the branch apex had N concentrations of 1.4% by 18 May 1994; however after grazing for ~400 sheep days/ha, the equivalent leaf/stem segments only had N concentrations of 0.6%.

Land capability. Should farmers fertilise saltland with nitrogenous fertilisers? The answer will depend on saltland capability. Barrett-Lennard *et al.* (2003) have suggested that saltland be divided into three different classes based on its productive potential:

- *Land of 'low' productive potential* will be dominated by clays of the valley floors in lower rainfall areas, and by shallow duplex soils and clays of the valley floors in higher rainfall areas. This land will be subject to high levels of salinity, waterlogging and inundation. In general, the soils in this capability class will be bare where there is severe inundation and will otherwise support self-sown samphire (*Halosarcia* species), or a patchy cover of highly salt tolerant annual grasses and forbs. These soils should not be planted to forage shrubs like saltbushes, as their rates of production will be low, and planting of saltland pastures on these sites is unlikely to be economically feasible.
- *Land of 'moderate' productive potential* will be dominated by duplex and gradational soils of lower salinity and waterlogging. These sites will be highly suited to the growth of saltland pastures. In winter-dominant rainfall regions with 300-400 mm rainfall saltbush species and small-leaf bluebush can be established by niche seeding or the planting of nursery-raised seedlings.
- *Land of 'high' productive potential* will be even less severely affected, and it will be possible to grow rows of saltbush with a substantial understorey of burr medic and/or balansa clover. These pastures are likely to be highly profitable.

Given the above, we believe that fertilisers should probably be focused on the land of 'high' productive potential. However, these will also be the kinds of sites where nitrogen fixation will be possible by annual under-storey legumes.

Acknowledgements:
We are deeply indebted to our host farmers - Keith Cater (Wubin), Colin Pearce (Meckering), Chris Walton (Yealering) and Michael Lloyd (Pingaring).

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Growth of *Atriplex nummularia* (old man saltbush) in a novel circular 'wheel' experiment on four saline sites in the WA wheatbelt. 2. Shallow groundwater and water use

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Introduction

Western Australian farmers have now constructed more than 11,000 km of deep open drains (Trewin, 2002) at costs of $5–10 per metre. This trial seeks to determine whether belts of halophytic vegetation can also have similar water-table lowering effects. Belts of trees are strongly constrained by saline groundwater; there is very little drawdown of water-tables at salinities greater than ~5,000 mg/L (George *et al.*, 1999). How are we therefore to lower water-tables where the salinity is that of seawater (about 6 times higher)? One solution may be to use belts of saltbushes to use the groundwater.

An experiment in small plots at Kellerberrin suggests that saltbushes can use 60-100 mm of groundwater at salinities up to seawater concentrations over two years (Barrett-Lennard and Malcolm, 1999). There is also farmer evidence that saltbushes can use enough water to 'freshen' sites enabling the growth of higher quality balansa and subterranean clover (Barrett-Lennard, 2002).

This paper is part of a larger investigation (see also paper 1 – Barrett-Lennard and Altman 2007), to examine the effects of site condition and plant spacing on saltbush growth and water use. The trials (at four sites) have been conducted in a novel design in which rows of old man saltbush (*Atriplex nummularia*) have been planted to converge like the spokes of a wheel at a common centre.

Materials and Methods

Layout of trials

The layout of the "wheel" trials, in which old man saltbush (*Atriplex nummularia*, variety Eyres Green) were planted at four sites (near Wubin, Meckering, Yealering and Pingaring) in rows at 30^o angles converging at a common centre has been previously described (Barrett-Lennard and Altman, 2007).

At each site, pairs of 3 m deep piezometers and neutron moisture meter access tubes were installed 2 m apart in bays 1, 3, 5, 7, 9 and 11.[4] (Bays are numbered clockwise, with bay 1 being between rows 1 and 2, etc.). Pairs of tubes were installed at 5 locations per bay. Location 1 was mid-way between adjacent saltbush rows and about 22 m from the centre of the wheel. Location 2 was within the saltbush row between plants 23 and 25 (numbered from the centre of the wheel). Locations 3, 4 and 5 were perpendicular to the saltbush row at distances 3, 6 or 12 m respectively from location 2.

[4] "Measurement" tubes were installed on 27-30 October 2003 (Wubin), 20-22 October 2003 (Meckering), 11-12 November 2003 (Yealering) and 19-20 November 2003 (Pingaring).

Additional 2 m deep neutron moisture meter access tubes "calibration bores" were installed in May 2005.[5] These were located in rows 2, 4, 6, 8, 10 and 12 between plants 14 and 15 (location 1) and 6 m perpendicular to there (location 2), and between plants 24 and 25 (location 3) and 6 m perpendicular to there (location 4).

Monthly measurements were made of groundwater levels (piezometers) and soil moisture at 20 cm depth intervals (measured using a neutron moisture meter – Campbell Pacific Nuclear Corp.).

Neutron moisture meter readings were calibrated by drilling two holes to 2 m depth immediately adjacent to the calibration bores – half the calibration bores were destroyed in this fashion in the winter of 2006[6], the other half will be destroyed in the summer of 2006/07. Two soil cores (40 mm in diameter, 2 m long) per calibration bore were extracted with a drill rig. These cores were encased in a Perspex sleeve as part of the drilling operation. They were cut into 20 cm segments on-site and were capped on either end of the Perspex sleeve to prevent evaporation. In the laboratory the samples were then weighed, oven dried, weighed again, crushed and analysed for salt ($EC_{1:5}$) using an electrical conductivity electrode (Wissenschaftlich-Technische Werstatten pH/cond 340i set). Selected samples were also analysed for chloride by the WA Chemistry Centre.

'Dense' plots were established in September 2004 at locations adjacent to the 'wheel' plot at Meckering and Yealering. The Dense plots consisted of 81 plants of the same clone of old man saltbush with plants at 2 m spacings planted in a 9 x 9 m array. A piezometer (to 3 m depth) and three neutron moisture meter access tubes (to 2 m depth) were installed in May 2005. These plots were fertilised with 'NPK blue' at the same times and rates as in the wheel rows (see Barrett-Lennard and Altman, 2007).

Each site was equipped with a rain gauge and an automatic weather station that measured temperature and relative humidity at hourly intervals.

Continuous water-level recorders (Wesdata) were installed in the piezometer of the Meckering 'Dense' plot and an adjacent control piezometer without saltbush in November 2006.

Results

Weather data

The amounts of rain that fell at each site during the period June 2004 to October 2006 decreased in the order Yealering (953 mm) > Meckering (840 mm) > Pingaring (800 mm) > Wubin (666 mm) (Figure 1). A substantial proportion (47-58%) of this fell in the months of June to September. However at each site there was an especially wet period in the summer of 2005/2006. About 150-180 mm of rain (17-23% of the total) fell in the months of January and February 2006.

[5] "Calibration" tubes were installed on 16 May 2005 (Wubin), 9–10 May 2005 (Meckering), 11–12 May 2005 (Yealering) and 12–13 May 2005 (Pingaring).

[6] Dates for the "winter drilling" were: 18-19 September (Wubin), 19-20 September (Meckering), 16-17 August (Yealering) and 14-16 August (Pingaring)

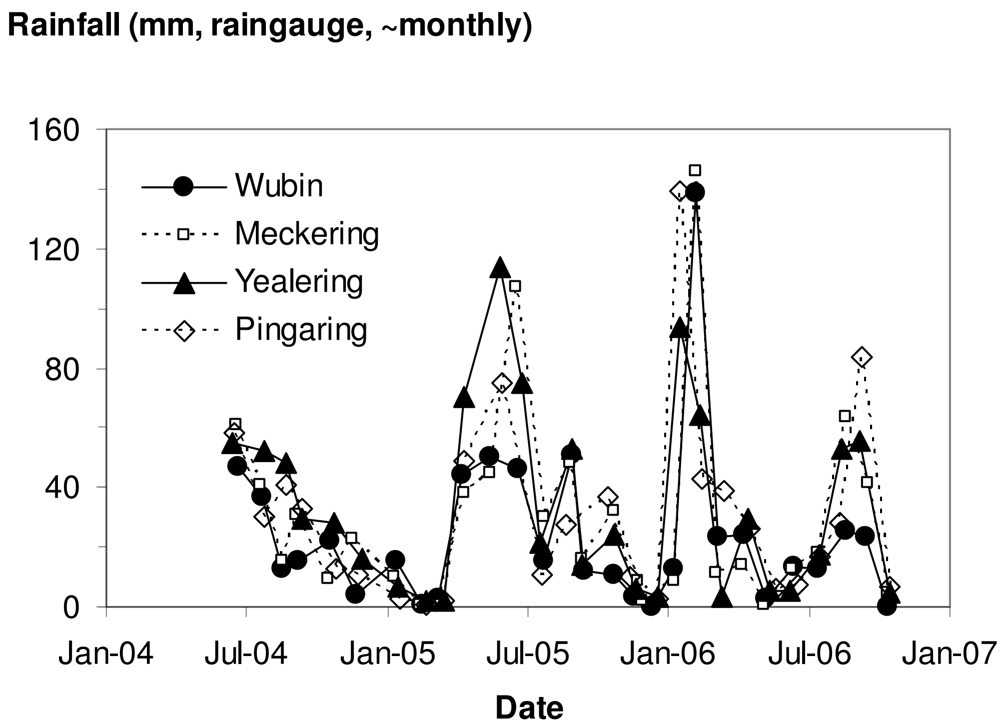


Figure 1. Rainfall (approximately monthly) measured with rain-gauges at each site.

Temperature and relative humidity were measured continuously at three sites (Wubin, Meckering and Pingaring) using weather stations and the data were used to calculate average monthly vapour pressure deficits (Figure 2). VPD's fluctuated seasonally. In winter the VPDs at all sites were relatively similar (around 2–4 kPa). In summer VPD values increased substantially, but the extent of this increase was affected by site location. Summer values were highest at the most northern site (Wubin; values of 20–28 kPa) and declined in the order Wubin > Meckering > Pingaring. VPD values were lower in the summer of 2005/06 (which had high rainfall) than in the summer of 2004/05.

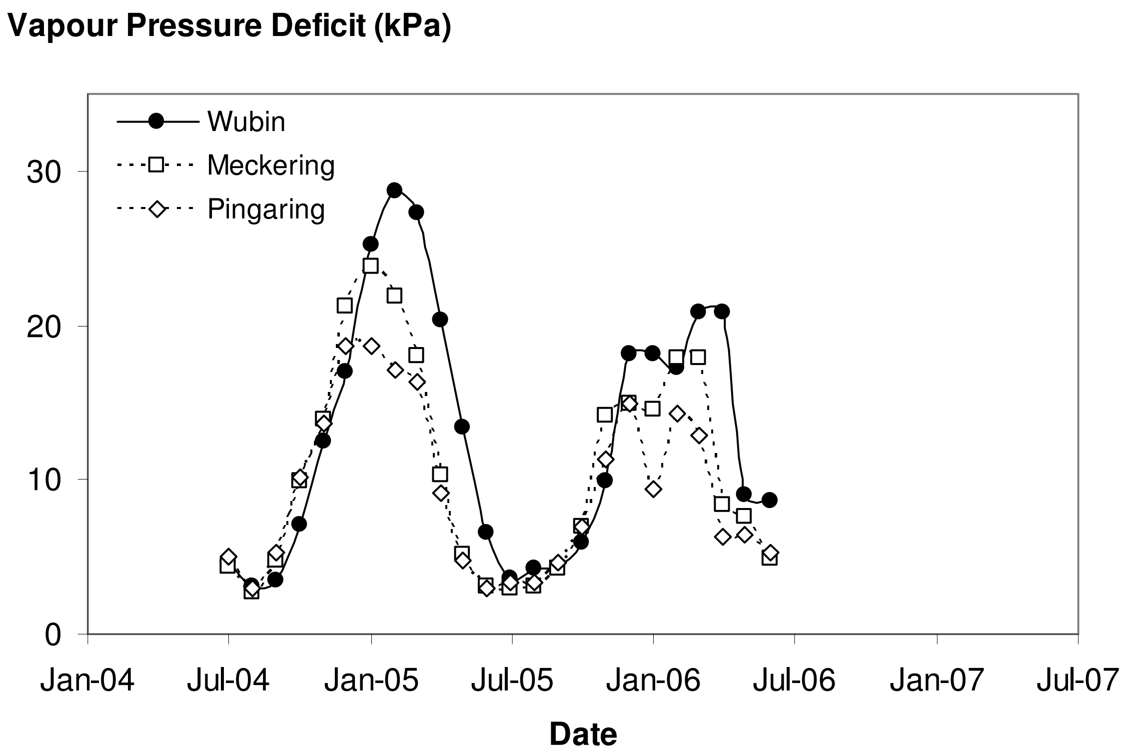


Figure 2. Vapour pressure deficits calculated from weather station data at three sites.

Depth, salinity and pH of groundwater

Water-tables were shallower at Yealering and Meckering (median values 0.93 and 1.01 m respectively) and deeper at Wubin and Pingaring (1.83 and 1.99 m respectively) (Figure 3). Water-tables fluctuated seasonally, but were within 0.3–0.5 m of the median 80% of the time. The sharpest rises in water-table were at Pingaring and Wubin when water-tables rose by 1.4 and 1.2 m respectively following the high rainfall event of Jan/Feb 2006 (Figure 3).

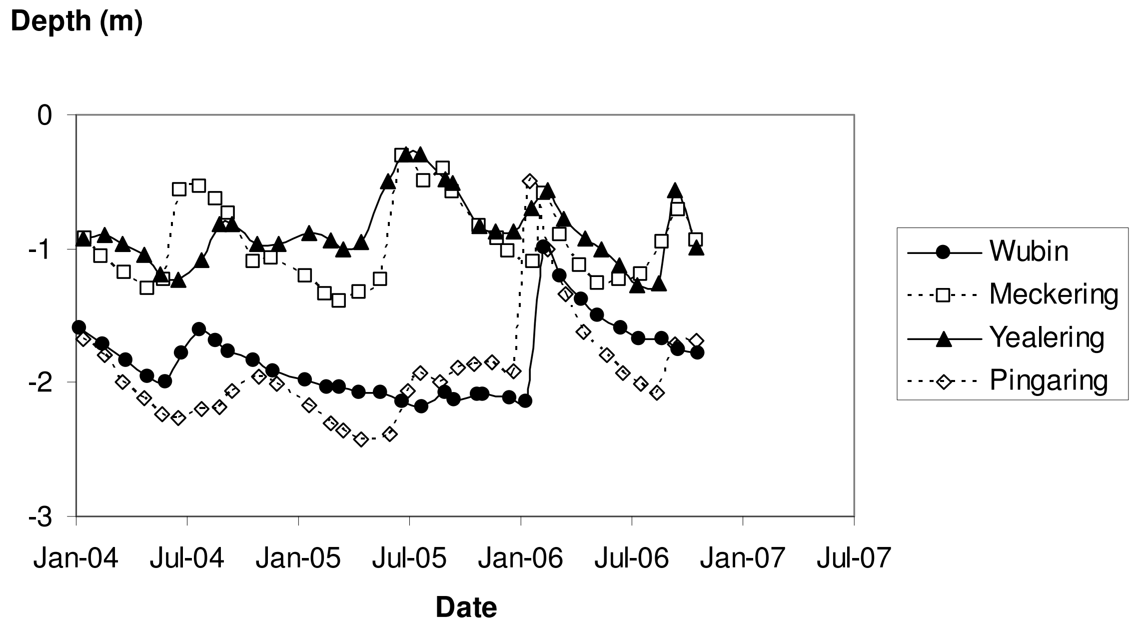


Figure 3. Average depth to the water-table at the four sites. Each point is the mean of 30 measurements.

The groundwater had a higher salinity at Pingaring and Wubin (median values 53 and 49 dS/m respectively) than at Meckering and Yealering (median values 17 and 15 dS/m respectively) (Figure 4). The greatest changes in groundwater salinity were a 37% decrease in EC_w at Pingaring and Meckering following the severe rainfall event in Jan/Feb 2006. However EC_w values returned to normal after 6 months (Figure 4).

The pH of the groundwater was highest at Meckering (median pH 7.3) and decreased in the order: Meckering > Pingaring (median pH 4.8) > Yealering (median pH 4.5) > Wubin (median pH 3.5) (Figure 5). The very low pH values, especially at Wubin are a potential constraint to plant growth. In adaptation trials of a range of *Atriplex* species and *Maireana brevifolia*, Malcolm and Swaan (1989) observed only 9% survival of plants after 10 years at a site with an average pH value over the upper 0.9 m of the soil profile of 4.6.

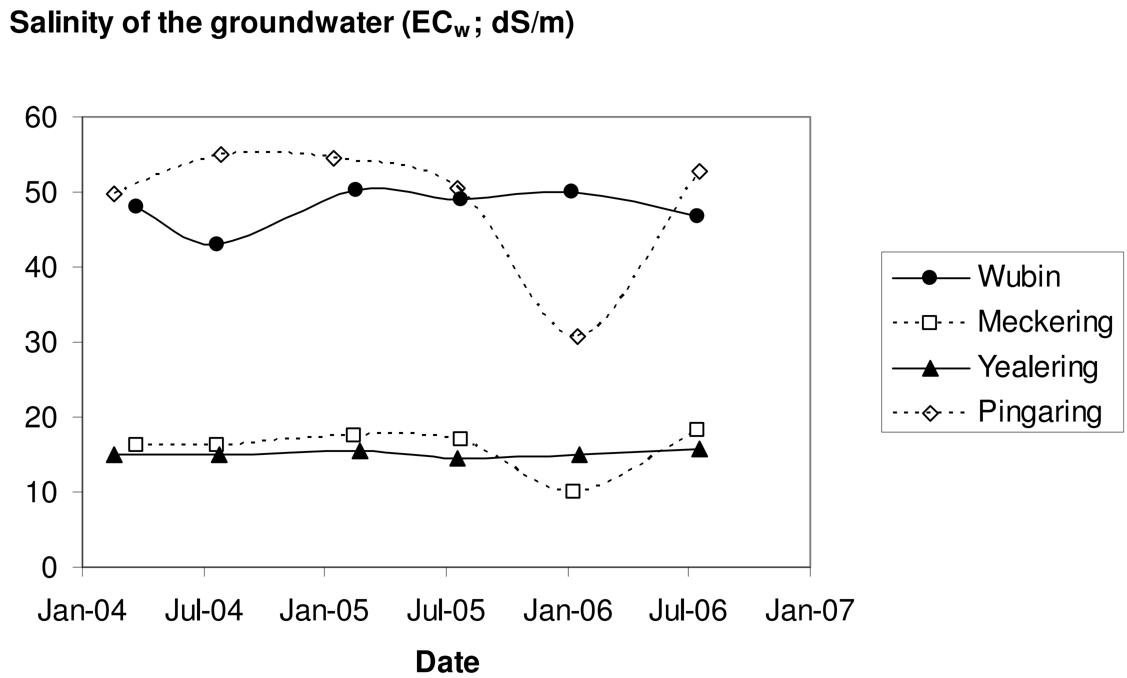


Figure 4. Average salinity (electrical conductivity) of the groundwater at the four sites. Each point is the mean of 30 measurements.

pH of groundwater

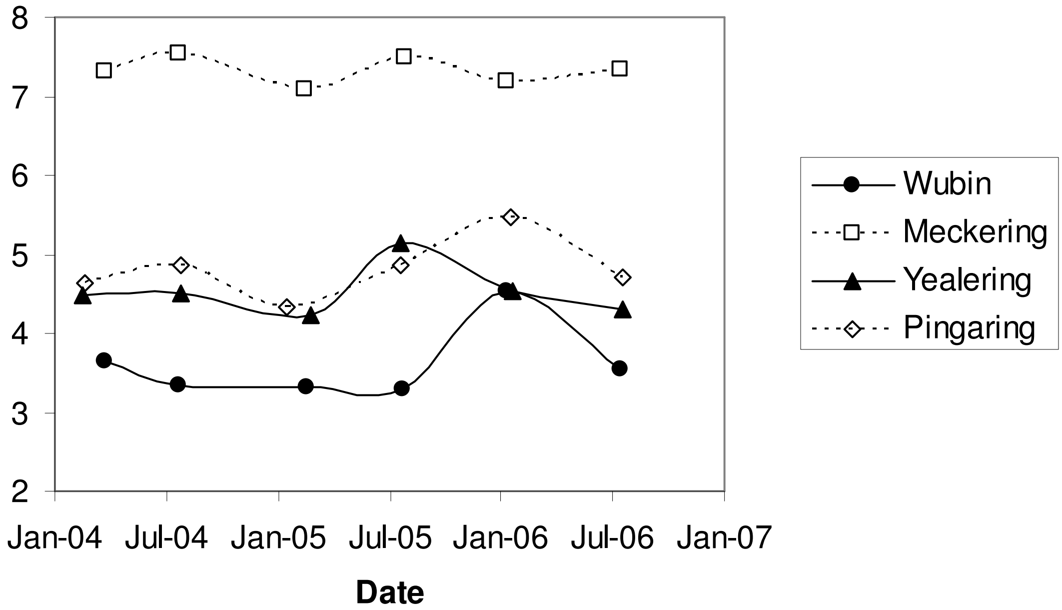


Figure 5. Average pH of the groundwater at the four sites. Each point is the mean of 30 measurements.

Water use by single rows of saltbushes

We are considering six proofs that saltbushes use groundwater, and because of the greater density of plants, this use is greater at the centre than the periphery of the wheels. We report on these below.

- *Soil beneath rows of saltbushes has lower moisture contents than adjacent soil away from the saltbush rows*. Figure 6 and 7 show the pattern of difference in neutron counts and total stored water over the upper 2 m of the soil profile between saltbush rows (location 2) and 6 m away (location 4). These data show that to some degree, the soils beneath rows of saltbush became drier at all sites in summer compared to winter (Figure 6). However, the effect only persisted at Wubin (Figures 6a, 7), the site with the combination of highest VPD in summer (cf. Figure 2) and deep water-tables (cf. Figure 3). In the summer of 2004/05, soils were up to 100 mm drier at Wubin, but only 25-31 mm drier at the other three sites. In the summer of 2005/06, the maximum effects were no greater (23–99 mm), presumably because of the high rainfall in Jan-Feb 2006 (Figure 1).

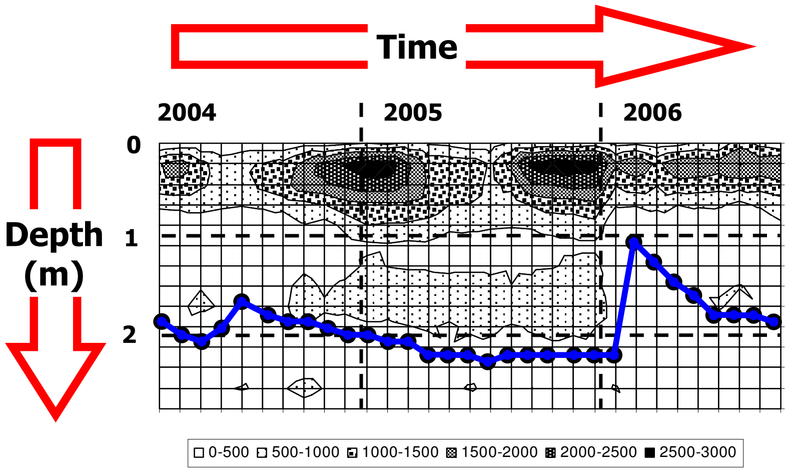
- *Soil beneath rows of saltbushes has deeper water-tables than adjacent soil away from the saltbush rows*. Effects of the single rows of saltbush on stored soil moisture were quite subtle and most manifest in summer. In Jan-Feb 2005, the average differences in the depths of water-table beneath the single rows of saltbushes compared to 6 m away were: 3.4 cm (Wubin), 1.3 cm (Yealering), 2.3 cm (Meckering) and 3.1 cm (Pingaring). Although all our plants were larger in Jan-Feb 2006, we were not able to detect greater effects because of the exceptionally high rainfall that occurred in those months. Further measurements of water-table difference will be made over the coming summer.

- *Salt accumulates in the root-zone beneath the rows of saltbushes*. All plants (including halophytes) take up water faster than salt; this leads to an accumulation of salt in the root-zone. We have now completed the first round of drilling (August/September 2006) for the calibration of our neutron moisture meter data. Our analysis of the collected soil samples shows clear evidence of salt accumulation in the root-zone at the two sites with the less saline shallow groundwater (cf. Figures 3 and 4), Meckering and Yealering (Figure 8). Salt concentrations ($EC_{1:5}$) increased beneath the saltbush rows at depths less than 100 cm. At Yealering the greatest increases (0.3–0.6 dS/m) occurred at 0–60 cm, whereas at Meckering greatest increases in salinity (0.5 dS/m) occurred at 40–80 cm depth (Figure 8). We expect greater differences in salt concentration to develop over the coming summer.

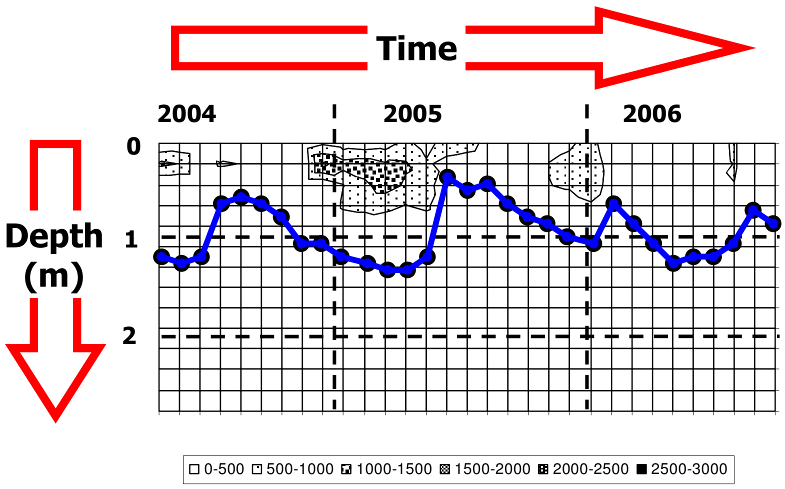
- *Plants have greater water deficits at the centre than at the periphery of the wheel*. One way of determining the water relations of plants is to measure the delta ^{13}C fractionation in the tissues. In January and July 2005 we measured this fractionation in 45 mm long segments of shoot tissue. Composites of 12 samples were established from plants 2, 3, 4, 5, 6, 8, 10 in each wheel. Their delta ^{13}C signatures were then correlated with their distance from the centre of the wheel. Delta ^{13}C signatures were higher (less negative) in winter than summer, and in summer, were lowest at Wubin, increasing in the order Wubin < Meckering < Pingaring < Yealering (Figure 9a,b). In summer, there was a strong effect of distance from the centre of the wheel on delta 13C signature at Wubin suggesting that the plants were more limited by the availability of water at the centre than the periphery of the wheel (Figure 9a). It was not possible to make further meaningful measurements of these signatures in the summer of 2005/06 because of the exceptionally high summer rainfall that occurred.

- *Plant shoot volumes are smaller at the centre than the periphery of the wheel*. As we have previously reported (Barrett-Lennard and Altman, 2007), although we have observed smaller plants at the centre than the periphery of the ‘wheels’, attributing the cause of this exclusively to water-deficits is far from clear. Nitrogen deficiencies have been invoked as a major cause of lower rates of plant growth at the centre of the wheels at our two sites with shallowest water-tables (Yealering and Meckering).

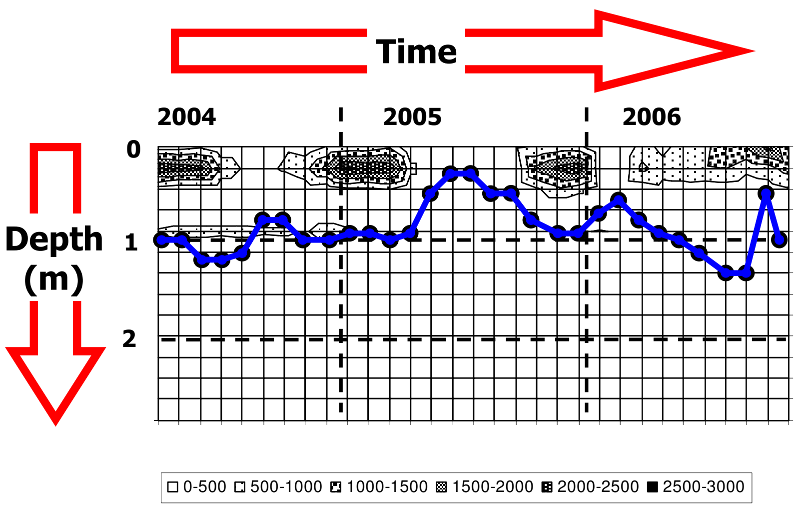
(a) Wubin



(b) Meckering



(c) Yealering



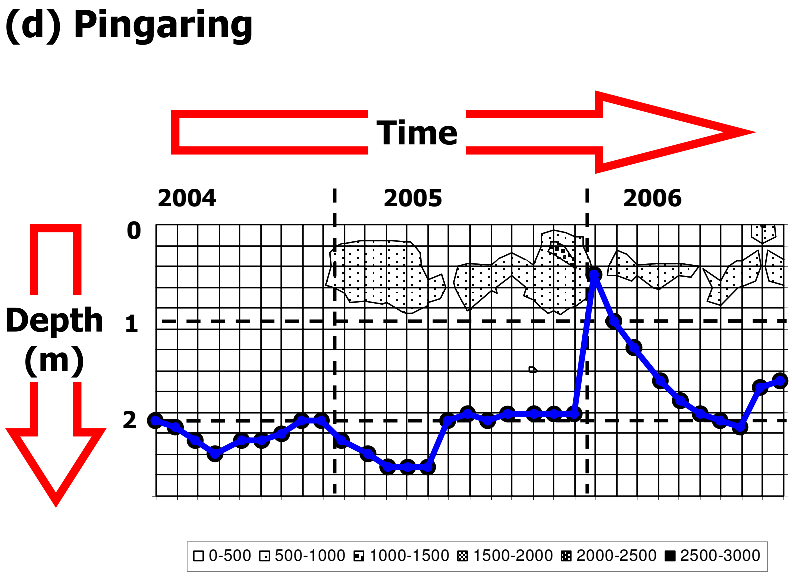


Figure 6. Difference in soil moisture (neutron counts) between single rows of saltbush (Location 2) and adjacent areas 6 m away (Location 4) at: (a) Wubin, (b) Meckering, (c) Yealering, and (d) Pingaring. The heavy line is the average water-table depth at the site (cf. Figure 3).

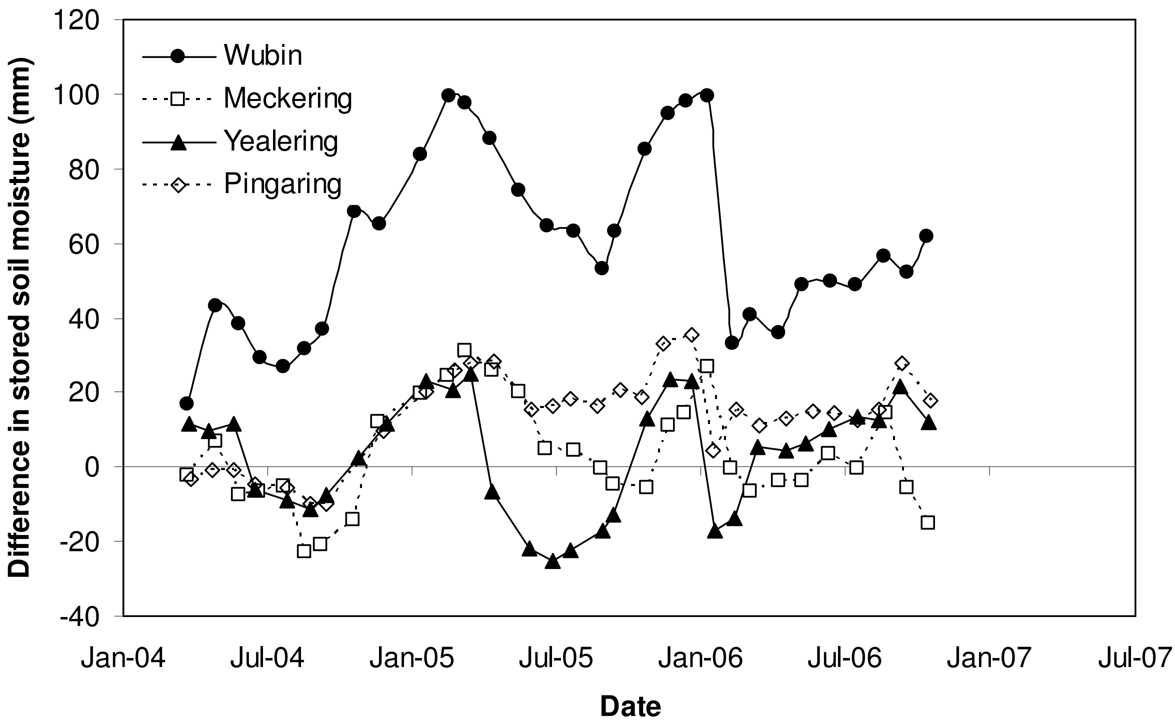
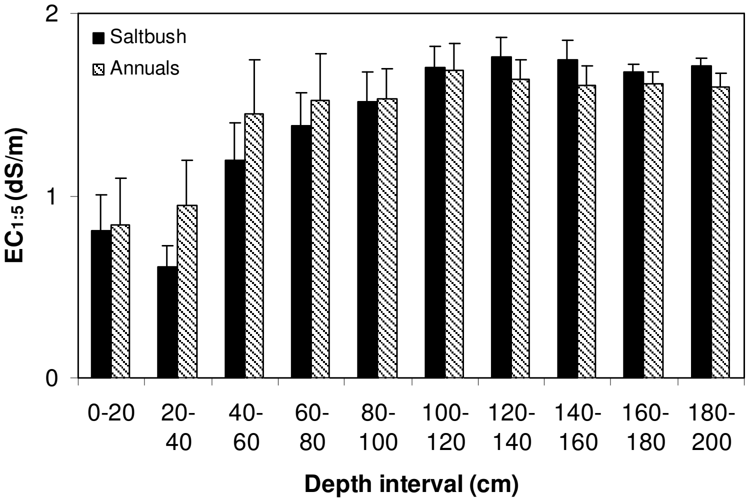
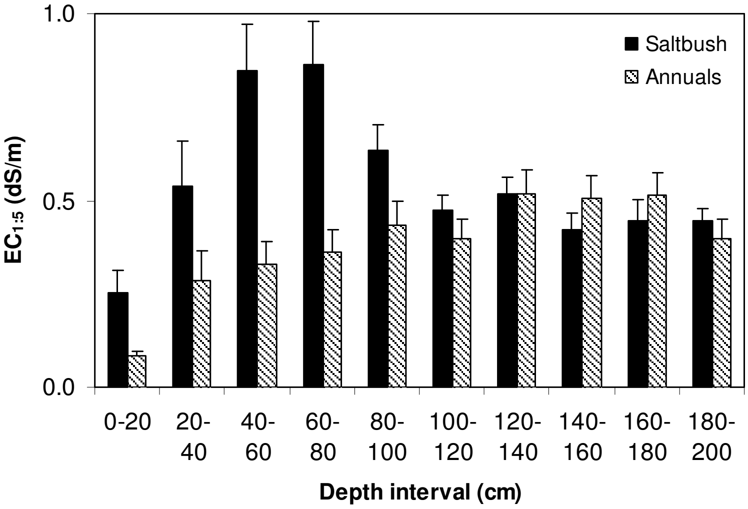


Figure 7. Estimated differences in stored soil moisture between saltbush rows (Location 2) and adjacent areas 6 m away (Location 4). Each point is the mean of six replicates.

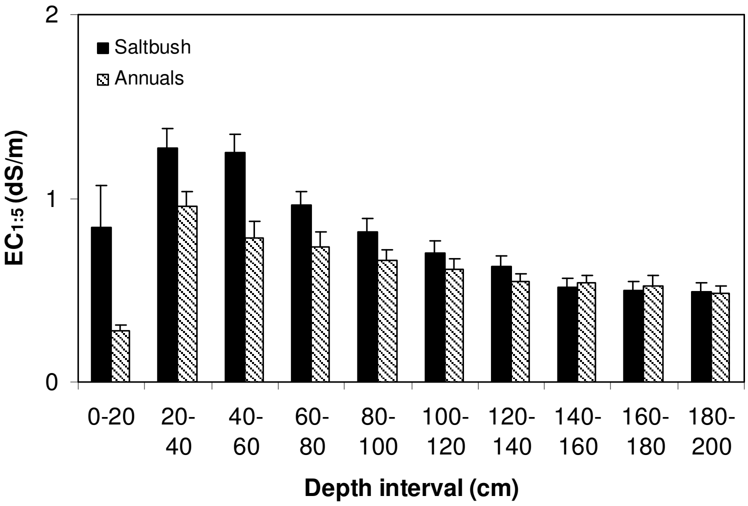
(a)


Saltbush
Annuals
2
1
0
$EC_{1:5}$ (dS/m)
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
160-180
180-200
Depth interval (cm)

(b)


Saltbush
Annuals
1.0
0.5
0.0
$EC_{1:5}$ (dS/m)
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
160-180
180-200
Depth interval (cm)

(c)


Saltbush
Annuals
2
1
0
$EC_{1:5}$ (dS/m)
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
160-180
180-200
Depth interval (cm)

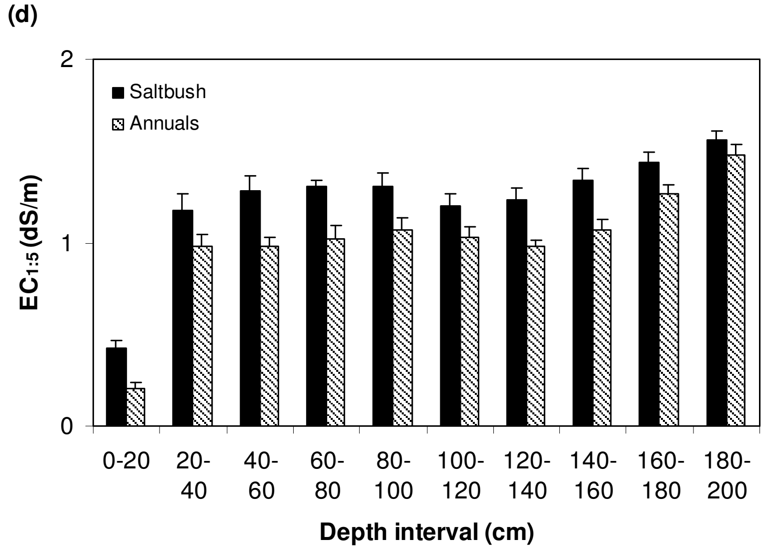


Figure 8. Salt concentrations ($EC_{1:5}$ values) in the winter of 2006 down the soil profile at: (a) Wubin, (b) Meckering, (c) Yealering, and (d) Pingaring. Soil cores were taken either in the saltbush row ("saltbush") or 6 m away ("annuals"). Each value is the mean $\pm$ sem of 12 values (6 locations, 2 replicates per bore).

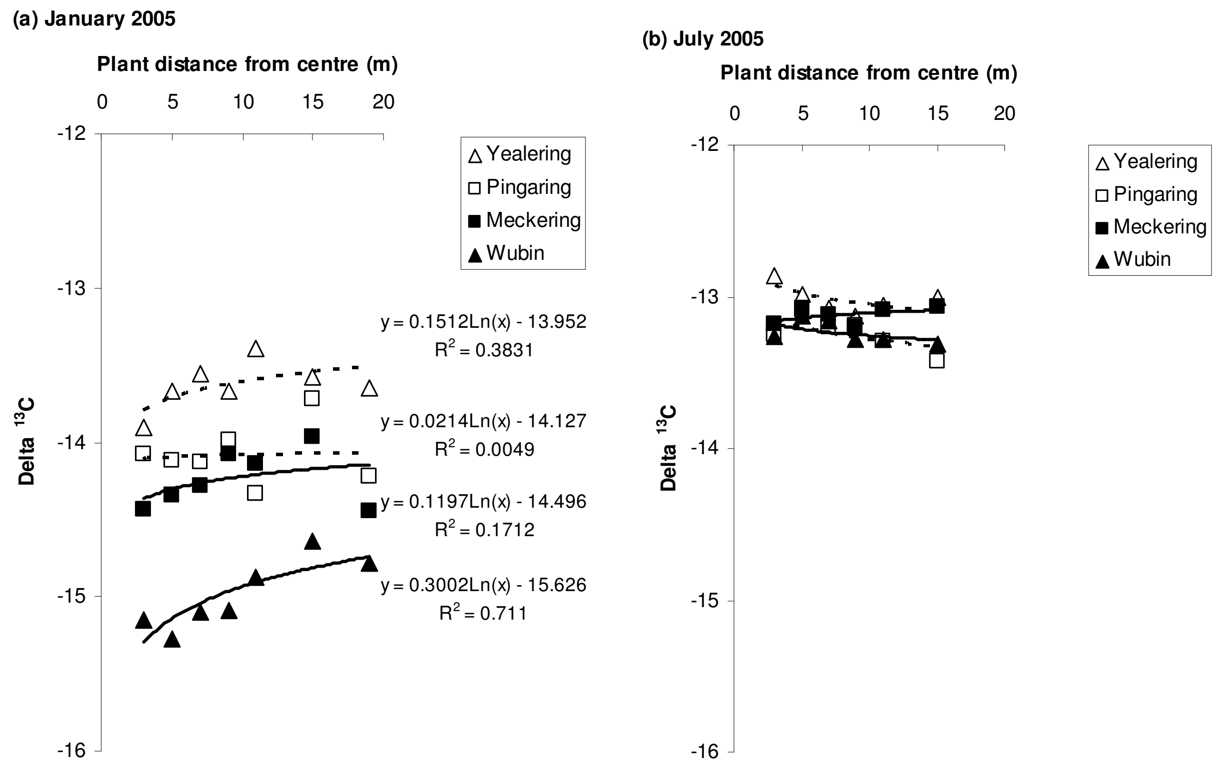
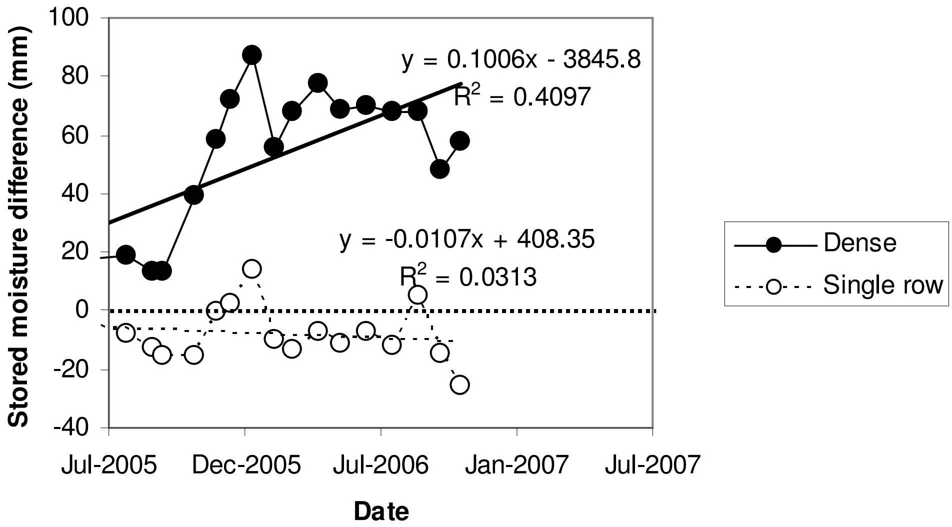


Figure 9. Delta ^{13}C signatures from shoot segments at the four wheel sites: (a) January 2005; (b) July 2005. Logarithmic trend lines have been fitted to the data. Each point is derived from a composite sample of the 12 plants at that location, measured twice.

Water use by dense stands of saltbush

In September 2004 we set ourselves the challenge of determining whether denser stands of saltbush could be more effective that single rows in lowering water-tables and drying out soil profiles. The ‘dense’ blocks at Meckering and Yealering are not replicated, so caution needs to be used in the interpretation of the results. At Meckering, the single rows of saltbushes had little effect on stored soil moisture compared to the neutron count background associated with annual pastures. In contrast, the ‘dense’ stand of saltbush dried the soil profile relative to the neutron count background; this effect was greater in summer (January 2006, 87 mm) than in winter (August 2005, 13 mm), and a regression line had a slope (Figure 10a). However, the lack of seasonal effects at Yealering incline us to the view that the effects of the ‘dense’ stands at this site were not very apparent (Figure 10b).

(a) Meckering



(b) Yealering

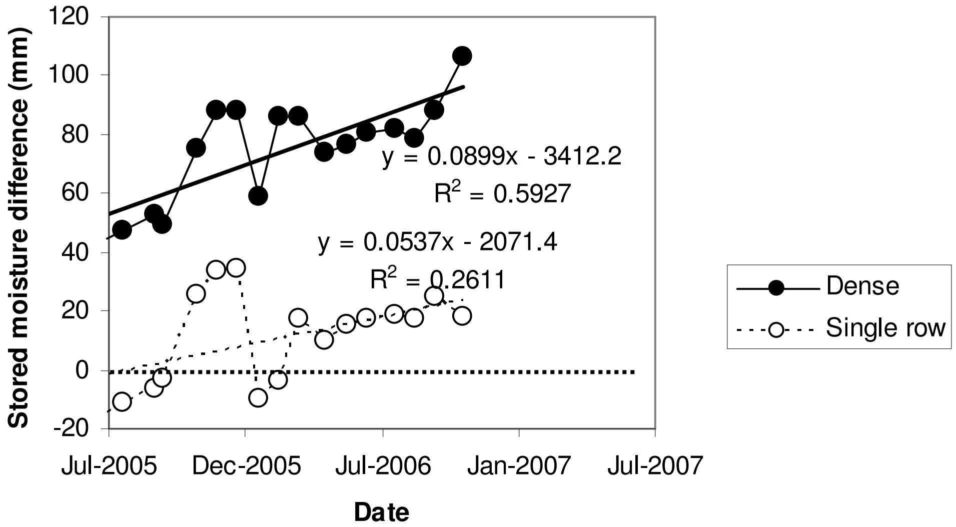


Figure 10. Difference in stored soil moisture (upper 2 m of the soil profile) between the "dense" block and the annual vegetation, or the single rows of saltbush and the annual vegetation at: (a) Meckering, and (b) Yealering.

Continuous water level recorders in the dense plot at Meckering in November 2006 showed a strong daily pulse, with water-tables declining by 60–80 mm between 0730 and 1830 hours and most of this loss being made up over night. In contrast, a continuous logger on a "control" bore showed none of this daily pulse (Figure 11). Further readings with continuous water-level recorders will continue over the coming summer.

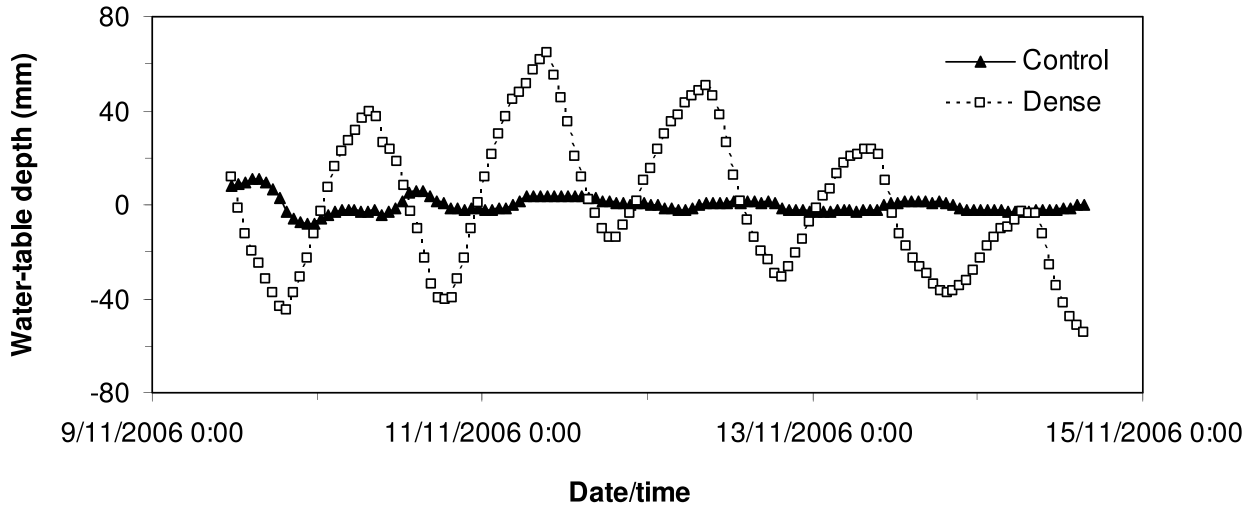


Figure 11. Diurnal fluctuations in water-table depth beneath 'dense' stands of saltbush compared with a 'control' bore at Meckering.

Discussion

Water use by saltbush

Under some circumstances saltbushes have the ability to dry out soil profiles, use groundwater and lower water-tables. Further comments are made about these three issues below.

Drying of soil profiles. There are two factors that affect the ability of plants like saltbushes to dry soil profiles; these are: (a) the depth of the water-table, and (b) the vapour pressure deficit. In our wheel experiments, the soil profiles were wetted from the soil surface on rainy days (less than 10% of the days of the experiment). However soil profiles were wetted by water from the subsoil continuously. The depth of the water-table is therefore a major determinant as to whether perennial vegetation is capable of drying a soil profile. At the two of our sites (Meckering and Yealering) where water-tables were shallow (median levels 0.9–1.0 m), no persistent soil drying was apparent (Figures 6b,c and 7). At the other two sites (Wubin and Pingaring) with deeper water-tables (median values of 1.8–2.0 m) the drying was affected by VPD in summer. At Wubin, VPDs reached levels of 20-30 kPa in summer (Figure 2) and after the summer of 2004/05, the soils were persistently 30–100 mm drier beneath rows of saltbush than 6 m away (Figures 6a and 7). In contrast, at Pingaring average monthly VPDs were 6–12 kPa lower in summer and the soils remained relatively moist compared with 6 m away (Figures 6d and 7).

Use of groundwater. One of the best tell-tale signs of the use of groundwater is salt accumulation in the root-zone. In general, all plants (including halophytes) take up water faster than they take up salt: this results in an increase in soil salinity close to the roots (Sinha and Singh 1974, 1976; Barrett-Lennard and Malcolm 1999). In the present experiments, the case for the use of groundwater is clearest at Meckering and Yealering. At both of these sites the groundwater was shallow (median values of 0.9 to 1.0 m) and of relatively low salinity (median values 15–17 dS/m). Salt accumulation in the upper 1 m of the soil profile clearly shows that these plants used groundwater at these two sites. At Wubin and Pingaring, where groundwater was deeper (median values 1.8 – 2.0 m) and more saline (median values of 49–53 dS/m), there was little evidence for salt accumulation in the root-zone. We expect to see further salt accumulation in the root-zone after the coming summer.

Lowering of water-tables. To some degree, the impacts of single rows of saltbush on water-table depth have been disappointing. However, the data from the continuous water-level recorders on the ‘dense’ plots at Meckering provide an explanation why the effects are so low. We estimate that the ‘dense’ plots have 1.7-times more leaf weight over a 20 m^2 area than single rows of saltbush.[7] With this increased leaf area transpiring water in November 2006, we have seen diurnal fluctuations in water-table of about 8 cm. However,

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[7] This estimate is based on the following two points.

1. In May 2006, we estimate that plants in the single rows of the “Wheel” at Meckering had ~0.60 kg dry leaf per plant, and these plants had root systems that occupied an area of ~20 m^2. In contrast, in the nearby “Dense” plot, the plants had an average leaf dry weight of 0.32 kg/plant, which is equivalent to ~1.6 kg of leaf per 20 m^2 area.
2. Observations of the wheel show that plant growth is decreased up to about the 10th plant from the centre. By trigonometry, we estimate that roots therefore compete for soil resources to distances of 4.9 m from the axis of the row. If plants are spaced 2 m apart, and their roots extend each side of the row, then they must occupy an area of 2 x 4.9 x 2 = 19.6 m^2.

most of the gains of the day are lost through lateral intrusion of water at night. Clearly, it will only be possible for saltbushes to cause substantial decreases in water-tables if they are planted on an extensive scale. The key factor leading to persistent gains will be to generate a high leaf area index (ratio of leaf area to soil surface area) with perennial plants on a paddock scale.

Design criteria for 'biological drains'

One of the differences between clays and sands lies in their ability to deliver water to the roots of transpiring plants. This will affect the design of saltbush alleys as 'biological drains'. In sands we will need many (say 8-12) rows of saltbushes to achieve water-table drawdown benefits, but in these soils of higher hydraulic conductivity, the rows of saltbush can be expected to exert an influence over a wide bay of adjacent land that could grow annual pastures (Figure 12a). However with lower hydraulic conductivity clays, the optimal alley configuration may be with fewer rows of saltbush (say 2-3) with relatively narrow adjacent bays of annual pastures (Figure 12b). In addition, the use of groundwater by the plants will be affected by three factors that affect the availability of that water: its depth, salinity and pH.

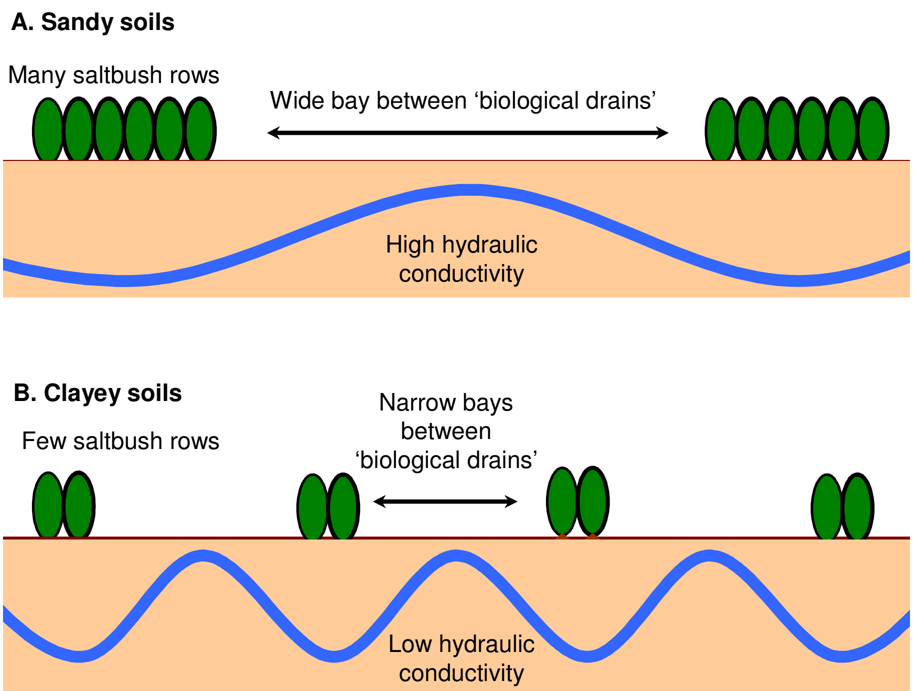

Figure 12. Early speculations about design criteria for the use of saltbushes as 'biological drains'. A. sandy soils, B. clayey soils.

Saltland capability assessment and species recommendations

One of the key issues facing us in the sustainable grazing of saline land is the prescription of plants to sites. We need low-risk processes to: (a) identify saltland of different capability, and (b) recommend plants for that land. We have previously suggested that halophytic plants be allocated to saltland of differing capability based on the assessment of levels of salinity and waterlogging (cf. the "salinity/waterlogging matrix", Figure 4.1 in Barrett-Lennard *et al.* 2003). The trouble with this approach is that both salinity and waterlogging vary widely on saltland both temporally and spatially (Smith, 1962, Teakle and Burville 1938, Barrett-Lennard *et al.* 2003). Furthermore, the growth of plants in the saline landscape may change the salinity of the soil or subsoil (Smith 1962, Teakle and Burville 1938, Heupermann, 1992, Thorburn 1996). This suggests (rather unfortunately) that we may need to make a range of measurements at a range of times and places before being able to categorise land capability – not at all helpful for a farmer who wants a quick and clear way forward.

The data from the wheel experiments presented here and in Barrett-Lennard and Altman (2007) suggest that there may be another way forward. We believe that there are three critical questions that need to be answered if plants are to be best allocated to saltland. These questions are:

- Can the plant use (take up and transpire) the groundwater?
- Can the plant's roots obtain oxygen?
- What other sources of water are available to the plant?

Further comments are made on the first two of these questions:

1. Availability of groundwater to support plant growth. Availability depends on the depth and salinity of the groundwater. Provided hypoxia does not occur (see next point), in the case of old man saltbush, highest growth occurred at Meckering (Barrett-Lennard and Altman 2007), the site with the shallowest and least saline water-table (Figures 3 and 4). Salt accumulation in the root-zone suggests that the plants were using considerable groundwater at this site (Figure 8b). Data from elsewhere suggest that *Atriplex* species are able to use groundwater up to EC values of about 50 dS/m (Barrett-Lennard and Malcolm 1999).

2. Avoiding hypoxia in the root zone. In general, plants have two strategies to avoid hypoxia in the root-zone: (a) grow in soils with sufficient internal drainage, or (b) develop physiological mechanisms to avoid root hypoxia. *Puccinellia ciliata* is a good example of a plant that adopts the latter strategy. In a recent investigation to determine why puccinellia occurs in lower parts of the saline/waterlogged landscape than tall wheat grass, Jenkins (2007) found that puccinellia can form more aerenchyma than tall wheat grass, has a better barrier to radial oxygen loss than tall wheat grass, and as a result has better regulation of Na^+ uptake under waterlogged conditions than tall wheat grass. Regrettably, *Atriplex* species do not appear to have access to these physiological adaptations. They must therefore seek out soils of sufficient internal drainage. Data from the current investigation shows that soil texture can affect the aeration of soils with shallow water-tables. In the sandy clay loam textured soil at Yealering, the air filled porosity at 30 cm depth was less than 10% about 80% of the time. In contrast in the sandy textured soil at Meckering the air filled porosity at 30 cm depth was less than 10% only about 15% of the time. This is important because 10% volume of air filled pores is the lowest value at which air can be exchanged in the soil (Wesseling and van Wijk 1957).

Acknowledgements
We are deeply indebted to our host farmers - Keith Cater (Wubin), Colin Pearce (Meckering), Chris Walton (Yealering) and Michael Lloyd (Pingaring).

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Estimating soil moisture and water-table drawdown by commercially managed stands of saltbush (*Atriplex* species) in south-western Australia

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Key outcomes

It can be difficult to measure soil moisture on saltland with the neutron moisture meter because low counts can be caused either by low moisture or high concentrations of chloride. We have considered this issue on a commercially managed stand of old man saltbush at Lake Grace in which chloride was a clear confounding factor. Comparisons of bores 13 m inside a saltbush stand with bores 13 m outside the saltbush stand showed that the saltbushes lowered water-tables by 16 cm in summer. Our best estimate of stored soil moisture suggested that the saltbushes dried out soil profiles by 50 to 150 mm compared with annual pastures.

Introduction

This paper examines the differences in stored soil moisture beneath commercially managed stands of saltbush. One of the challenges to using the neutron moisture meter to estimate changes in stored soil moisture on saltland is that the readings from the machine are affected by changes in both the volumetric water content of the soil and the volumetric concentration of chloride (Greacen, 1981). How are we therefore to ascribe changes in neutron counts to saltland treatments like revegetation?

This paper is part of a larger study to examine the benefits to saltland drainage of revegetation with saltland pastures (see also Barrett-Lennard and Altman, 2007). We examine here the effects of a commercially managed stand of saltbush on water-table drawdown and stored soil moisture. The analysis has been confounded by the fact that although the landscape was flat, the areas planted to saltbush had far higher concentrations of salt in the soil profile than the adjacent areas without saltbush.

Materials and Methods

This trial was conducted on “Bundilla”, the property of Michael and Margaret Lloyd at Pingaring. The trial is sited on an area at high risk of salinity. The saltbushes were planted in August 1997 at a rate of ~2800 plants/ha and the stands were managed as a commercial operation being grazed by sheep as required.

The trial site consisted of two dense stands of old man saltbush (*Atriplex nummularia*) separated by about ~90 m of annual pasture. Drilling was done on 22-23 April 2004 within the stands of saltbush or within the annual pasture area along lines ~13 m from the saltbush/annual boundary. Piezometers were dug along these lines to depths of 3 m (4 replicates) or 4 m (2 replicates). Neutron moisture meter access tubes were installed adjacent to each 3 m deep piezometer.

A salinity survey was conducted over the entire site on 1 June 2006 on a 10 x 10 m grid. Measurements were made of the bulk soil conductivity using the EM38 and the EM31. At the same time 11 holes were dug to a depth of 1 m with a soil auger to establish calibration curves between apparent electrical conductivity (EC_a) values recorded with the EM38 and EM31 and EC_e values on extracted soil samples. In addition EM38 and EM31 readings were taken at all piezometers to determine if correlations could be established between EC_a values and the salinity of the groundwater.

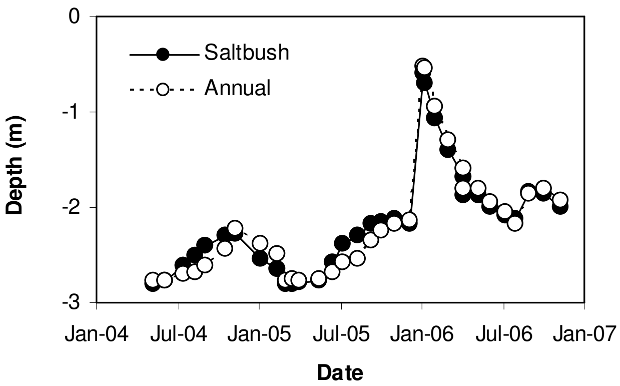
Results

Depth of groundwater

Observations have now been made at the site for 33 months. During this time water-tables at the site have been mostly in the range 2.2 to 2.8 m. However, with 180 mm rainfall in Jan/Feb 2006, water-tables briefly rose to ~0.5 m (Figure 1).

Interestingly, in the springs of 2004 and 2005, the water-tables were up to 0.2 m lower in the annual pasture than in the saltbush, however this situation was reversed in each subsequent autumn. Water-tables are presently at depths of 1.9–2.0 m and are falling.

(a)



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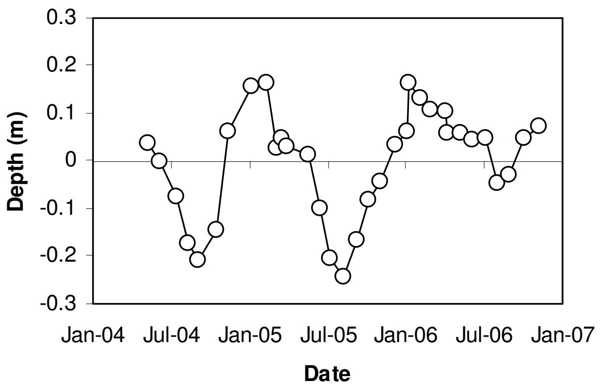

Figure 1. Effects of saltbush on depth to water-table: (a) average depth to water-table beneath saltbush and annual pasture, (b) difference between saltbush and annual pasture. Bores were 3 m deep and located ~13 m either side of the saltbush/annual pasture boundary. Data are the average of 4 bores.

Salinity of groundwater. The salinity of the groundwater from the 3 m deep piezometers has been measured 4 times at about 6 monthly intervals since the establishment of the trial (Figure 2). During this time, values have been consistently higher beneath the saltbush (55–62 dS/m) than the annuals (22–46 dS/m).

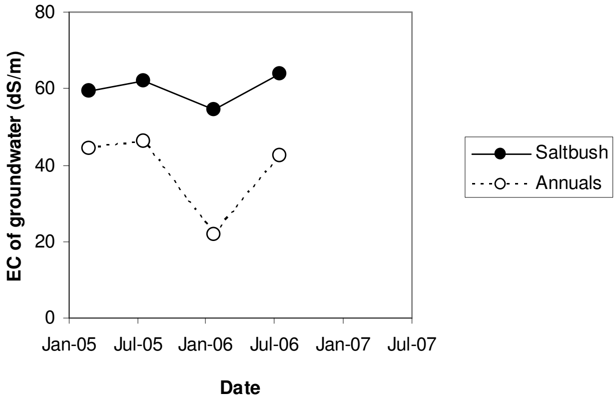

Figure 2. Electrical conductivity of the groundwater from 3 m deep piezometers beneath saltbush and annual pastures.

Soil and groundwater salinity survey

EM38 and EM31 measurements were 27–63% greater beneath the bays of saltbush than in the annual pasture area between. However, there was no correlation between ECa readings and ECe readings over the upper 1 m of the soil profile – the increased salt concentrations must have occurred at greater depths. In the calibration holes, there was no significant effect of depth or treatment on ECe values to 1 m. In contrast to upper soil salinity, there were significant correlations between EM31 or EM38 readings and the ECw of the groundwater sampled from the 3 m bores on 20 July 2006 ($P < 0.001$). The line of best fit was:

ECw = 0.2629*EM31horizontal - 3.2085 ($r^2 = 0.92$; n = 10)

Using this line of best fit, and with EM31 readings on a 10 x 10 m grid, we estimate that the salinity of the groundwater beneath the saltbushes was 64.2 $\pm$ 0.7 (sem) dS/m (n = 97), but with only annual pastures, the ECw of the groundwater was 43.6 $\pm$ 0.6 (sem) dS/m (n = 119)

Soil water content

Characterising the probe

Before collecting data from the field, each month our neutron moisture meter was characterised with a shield count and a count at a depth of 50 cm with a tube inside a drum of water. Shield counts remained consistent throughout the experiment. Drum counts were affected by the temperature of the water according to the correlation:

Counts = 19.72 * T + 21581 ($r^2 = 0.77$; n = 22) – equation 1 where T is the temperature of the water (well stirred) in the drum in degrees Celsius. What this equation shows is that at 100% volumetric water content, an increase in temperature from 10 to 20 degrees would be expected to increase neutron counts by ~1%. This is clearly a negligible error.

Adding salt (NaCl) to the water in the drum decreased neutron counts according to the equation:

Counts = -79.744 * ECw + 21115 – equation 2

where ECw is the electrical conductivity of the salt solution in dS/m. A similar correlation was obtained for KCl but not $NaNO_3$, clearly indicating that the cause of the effect was chloride. What this equation shows is that a change in a soil with a specific yield of 10%, an increase in the salinity of the groundwater from 0 to 55 dS/m (the approximate salinity of seawater) would decrease neutron counts by ~21%. This is clearly *not* a negligible error.

Field results

Neutron moisture meter traces between the saltbush and annual pasture diverged strongly down to a depth of 1.9 m (eg. see data for February 2005 in Figure 3). However, it was curious that there were differences in neutron counts even below the water-table. For example in Figure 3, the water-tables were at 2.5–2.6 m depth, yet even below this depth, neutron counts were 5% lower with saltbush than the annuals. We believe that this effect is caused by salinity affecting neutron counts close to the water-table.

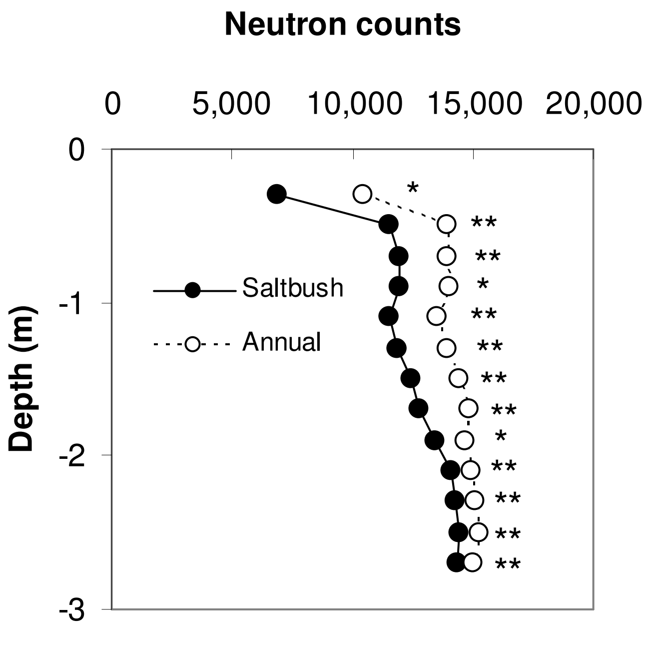

Figure 3. Average neutron counts in February 2005 beneath saltbush and annual pasture. Data are the average neutron moisture meter readings of four access tubes. Average depths of the water-table were 2.64 m (saltbush) and 2.48 m (annuals). Values are significantly different at $P < 0.05$ (*) or $P < 0.01$ (**).

We have not yet been able to complete our calibration of neutron moisture meter readings versus volumetric water content. However, estimates of *differences* in stored soil moisture are possible based on the drum counts described above. If we assume that saltbush and annual treated neutron access tubes have absorb/transmit equal numbers of neutrons then the differences in neutron counts between treatments can be converted to a difference in volumetric water content on the basis that 100% water is equivalent to ~21,877 counts. Based on this assumption, the differences in the moisture profiles for February 2005 (Figure 3) would have been due to about 207 mm of moisture difference between the areas with saltbush and the areas with annual pasture over the depths of 0.3 to 2.7 m. However, we have already seen that the saltbush and annual pasture areas had very different salinities in the groundwater (Figure 2) and this decreases neutron counts (equation 2). Our estimate of 207 mm must therefore be seen as an "upper limit" to the moisture difference. If we assume that the salinity error applied at all depths in the soil profile, then the moisture difference in February 2005 would have been due to 108 mm of moisture. However, we have already seen that there was no discernable difference in soil salinity between the two treatments over the upper 1 m of the soil profile, so the 108 mm difference is clearly a "lower limit". We have estimated a "plausible" difference by assuming that the salt concentration difference between the treatments increases linearly between 1 and 2 m depth. The plausible value for the difference in moisture between treatments in February 2005 is estimated to be 154 mm.

Figure 4 shows a plot against time for the entire collected dataset of the upper limit, lower limit and plausible value for the difference in moisture between the saltbush and annual pasture treatments. The difference in stored soil moisture between the saltbush and annual pasture treatments fell following the 180 mm rainfall event in January/February 2006 but those differences have at least partly returned as the soil profiles have dried out since.

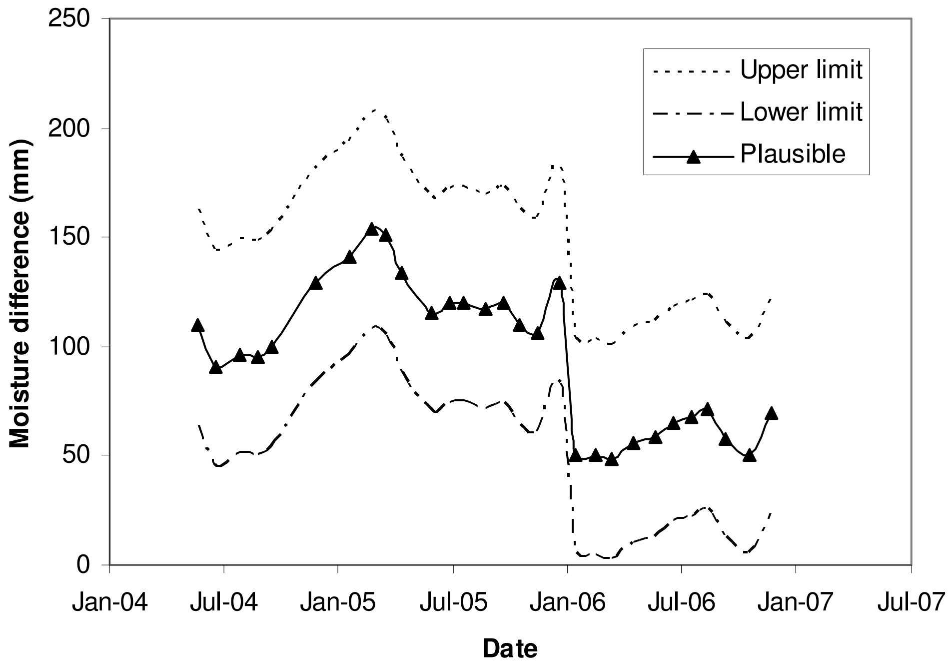

Figure 4. Estimated differences in moisture content in the soil profile (0.3 – 2.7 m) depth between the saltbush and annual pastures. The three lines have been calculated as described in the text.

Discussion

Calibration or more monthly measurements? Our observation that neutron counts are affected by salinity and soil moisture indicates that there is a strong need for a neutron moisture meter calibration curve for this site. The required drilling will be undertaken this summer. The samples collected to calibrate for soil moisture will also be analysed for salinity.

Salinity in a spatial context. Our observation that groundwater salinity is higher beneath the saltbushes than the annuals (Figure 2) might be indicative of groundwater use by saltbushes and a consequent increase in salinity in the root-zone (cf. Thorburn, 1996; Heupermann, 1992, Barrett-Lennard and Malcolm, 1999). This issue clearly needs further study as there is a risk that salinisation on this scale can impact on the long term sustainability of revegetation. We would also expect to see lower use by halophytes of groundwater of EC_w 60 than 40 dS/m.

Evidence for stem flow? We continue to be intrigued by the fact that water-tables beneath saltbushes are shallower in spring and deeper in autumn compared to the annual pasture (now observed over two successive years – Figure 1). We wonder if these data could be indicative of stem flow. There are indications that some 'vase shaped' plants in arid environments irrigate their root zones by intercepting rainfall with their leaves and directing it down their stems and through gaps at root/soil interface to the deep roots (eg. Nulsen *et al*. 1986). If so, these effects could mitigate against substantial groundwater use by the shrubs in winter. One the other hand, this irrigation of the deep roots with fresh rainwater could help plants without the adverse effects of salt accumulation in the root-zone discussed above.

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Ecological transects to interpret zonation of pastures species on saline waterlogged land in south western Australia

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Key outcomes

Our project has clearly shown that economic gains can be made by focusing revegetation on saline landscapes capable of growing perennials (for water use) with a legume understorey. The growth of saltland pasture species is affected by two highly variable soil conditions – salinity and waterlogging. How can we diagnose saltland to ensure that solutions target landscapes with greatest productive potential? Our work suggests that reasonable predictions can be made for perennials based on the bulk conductivity of the soil over the upper 50 cm and the depth to the water-table. It may therefore be possible to base saltland capability assessment substantially on an EM38 survey and a backhoe pit to determine the depth and salinity of the groundwater.

Introduction

Saltland is generally affected by salinity and waterlogging, and the combination of these stresses increase salt concentrations in the shoots, which affects plant growth and survival (Barrett-Lennard, 2003). This has lead us to suggest that halophytic plants be allocated to saltland of differing capability based on the assessment of levels of salinity and waterlogging in the "salinity/waterlogging matrix" (see Figure 1). The trouble with this approach is that both salinity and waterlogging vary widely on saltland both temporally and spatially (Smith, 1962, Teakle and Burville 1938, Barrett-Lennard *et al*. 2003).

Salinity fluctuates seasonally as a result of leaching by rain and salt accumulation at the soil surface through capillarity (Smith 1962). It is also affected by soil cultivation treatments (Smith 1962), the mulching effects of clumps of annual plants at the soil surface (Teakle and Burville 1938; Smith 1962), and the accumulation of salt in the root zones of deeper-rooted perennial plants (Heupermann, 1992, Thorburn 1996, Barrett-Lennard and Malcolm, 1999).

Waterlogging causes oxygen deficiency (hypoxia) in soils primarily because gases diffuse ~10,000 times slower through water-filled than gas filled pores. Hypoxia begins to affect plant growth as the air-filled porosity in the soil decreases to values below 10% (Wesseling and van Wijk, 1957) and this will occur at different heights above the water-table, depending on soil texture (cf. Barrett-Lennard and Altman, 2007).

The above analysis (rather unfortunately) that we may need to make a range of measurements at a range of times and places before being able to categorise land capability – not at all helpful for farmer who need quick diagnoses of salinity problems so that they can target remedial action.

One approach may be to focus on techniques with lower levels of variation. Electromagnetic induction techniques can be used to estimate electrical conductivities of many cubic meters of soil. For example the EM38 derives a measure of the conductivity of the soil to depths of ~40 or ~100 cm over a width of 1.5 m. EM38 readings are affected by the salinity, texture and moisture content of the soil, but reasonable calibrations can be achieved against bulk EC_e values.

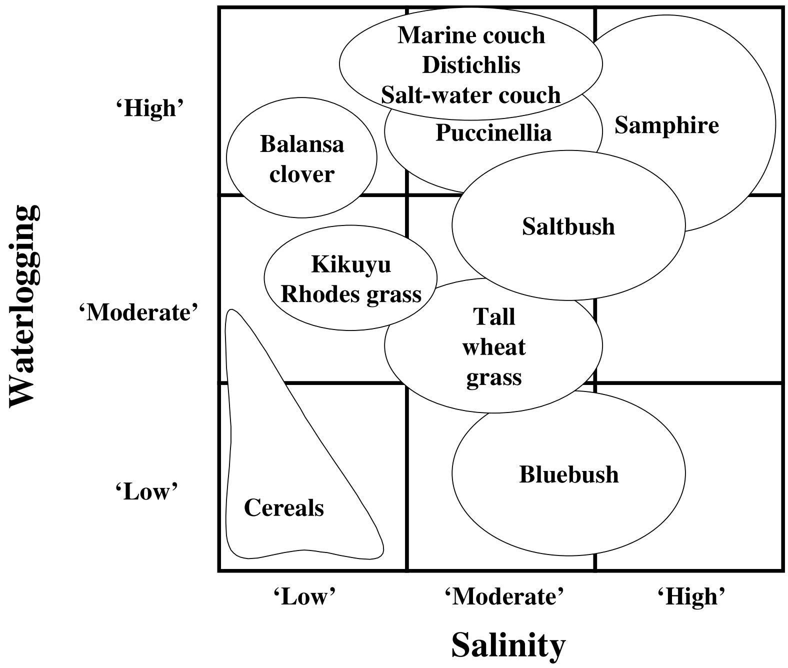

Figure 1. Matrix of plant adaptation to salinity and waterlogging (after Barrett-Lennard *et al*. 2003).

Similarly, although hypoxia in soil profile in saline landscapes is highly variable, water-table depth can be easily determined by monitoring networks of shallow bores. There are indications that annual plant cover on saline land can be related to the depth of the water-table. In an investigation of 29 sites in the Western Australian wheatbelt, Nulsen (1981) found that there was a significant relationship between vegetation cover class and the depth of the unconfined water-table (Figure 2), but there was no relationship between vegetation cover class and any other parameter measured.

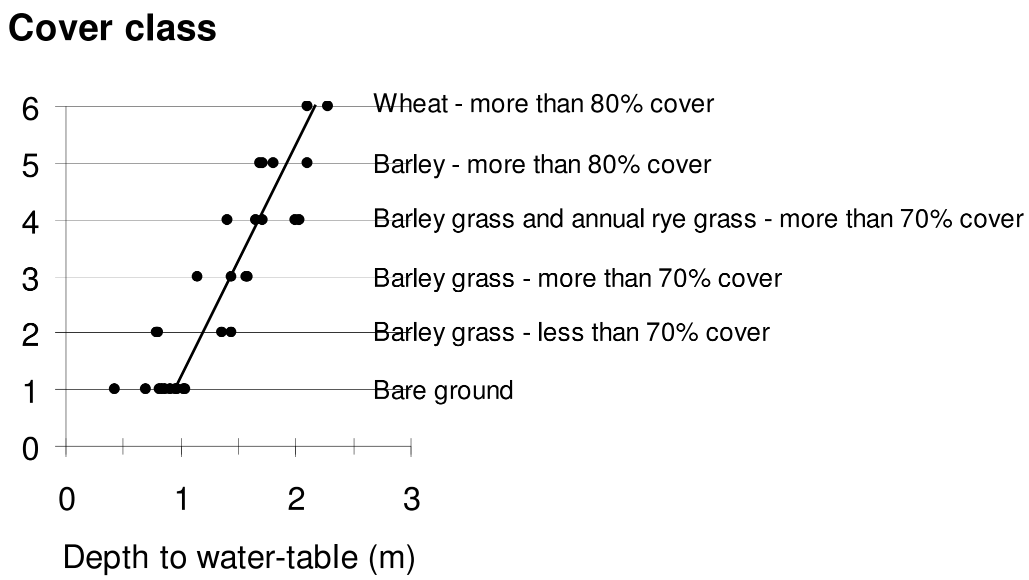

Figure 2. Relationship between annual vegetation cover class and depth of the water-table with south western Australia (after Nulsen 1981).

This paper describes an attempt to relate the location of 6 perennial species to saltland of differing salinities and depths to the water-table at four saltland sites in south-western Australia. We suggest that it may be possible to allocate saltland revegetation treatments to sites based on a relatively limited number of site measurements.

Materials and Methods

The Transect trials were conducted with six perennial plant species: samphire, river saltbush (*Atriplex amnicola* Paul G. Wilson), small leaf bluebush (*Maireana brevifolia*), saltwater couch (*Paspalum vaginatum*), rhodes grass (*Chloris gayana* cv. Pioneer) and lucerne (*Medicago sativa* cv. Sceptre). After planting, our samphire species was identified as *Halosarcia* sp. Angel Fish Island (cf. Shepherd *et al*. 2005). This species is only known to occur at Lake Carey and Lake Minigwal in the Eastern Goldfields of Western Australia (K. Shepherd. pers. comm. 2006). Notwithstanding this, we have assumed that its ecological zonation will be indicative of that of the naturally occurring samphires that occur in the WA wheatbelt, especially *Halosarcia pergranulata*.

Our experiments were conducted as “transects” on four sites in south western Australia – Meckering, Wubin, Yealering and Pingaring. Plants were raised in the glasshouse and planted at marked locations in mid-September/early October 2003 in 5 x 5 m plots running down ‘transects’ in what were presumed to range from a non-saline/non-waterlogged high side to a saline/waterlogged low side.

The first planting (phase 1) was in late Spring 2003 and monthly monitoring of survival indicated mortality in some species over the summer of 2003/04 and the following autumn. Furthermore, some species continued to grow and overwhelmed adjacent placements. In June 2004, we therefore hand stripped the largest plants at three trial sites (Yealering was grazed and no harvest was possible) and all placements were then replanted with the original species (phase 2). Sites were reharvested and subsequently grazed in February/March 2005.

Soil salinity was measured on four occasions (November ’03, June ’04, June ’05 and Sep/Oct ’05) using an EM38. Calibration curves were established between EM38 readings in the vertical and horizontal positions and sampled soil (7–14 holes per site/time) at depths to 50 cm. These calibration curves were generally multiple linear regressions with *P* values between < 0.001 and 0.036). It was assumed that the bulk conductivity of a 5 x 5 m plot could be calculated as the average of the EC^e values at its four corners.

Depths of the water-table were measured at monthly intervals from nine bores (3 rows of 3 through the site). A krigging process was used to estimate the water-table depth in the summer of 2003 and the winter of 2004 at each 5 x 5 m plot.[8]

Plant survival and plant growth (shoot dimensions) were measured at monthly intervals. For plants with an erect shoot (saltbush, bluebush, samphire, lucerne) “shoot volume” was calculated as $\pi*D_1*D_2*H/6$ (where D_1 is shoot horizontal diameter, D_2 is the diameter at right angles to D_1, and H is shoot height). For plants with a prostrate growth habit (salt water couch and rhodes grass) “shoot surface area” was calculated as $\pi*D_1*D_2/4$. Our analysis of ecological zonation is based partly on plant survival and partly on growth. In the current work, we have assumed that the plants with most rapid growth can be identified on the basis of their “shoot volume” and “shoot surface area”.[9]

Grazing of the plots was conducted opportunistically using the farmers’ sheep. Plots were grazed during the experiment as follows:

- Wubin – not grazed by sheep.
- Pingaring – grazed by sheep on 17-19 March 2005.
- Meckering – grazed by sheep on 9-23 March 2005.
- Yealering – grazed by sheep on 1-16 June 2004 and 29 June-20 July 2005.

Results

Weather data

The amounts of rain that fell at each site during the period June 2004 to October 2006 decreased in the order Yealering (953 mm) > Meckering (840 mm) > Pingaring (800 mm) > Wubin (666 mm) (Figure 3). A substantial proportion (47-58%) of this fell in the months of June to September. However at each site there was an especially wet period in the summer of 2005/2006. About 150-180 mm of rain (17-23% of the total) fell in the months of January and February 2006.

[8] Further details need to be provided by Sarita.
[9] For this to be valid, the relationships between “shoot volume” or “shoot surface area” and shoot dry weight need to be consistent across sites. The degree to which this is true will be justified in the next version of the paper.

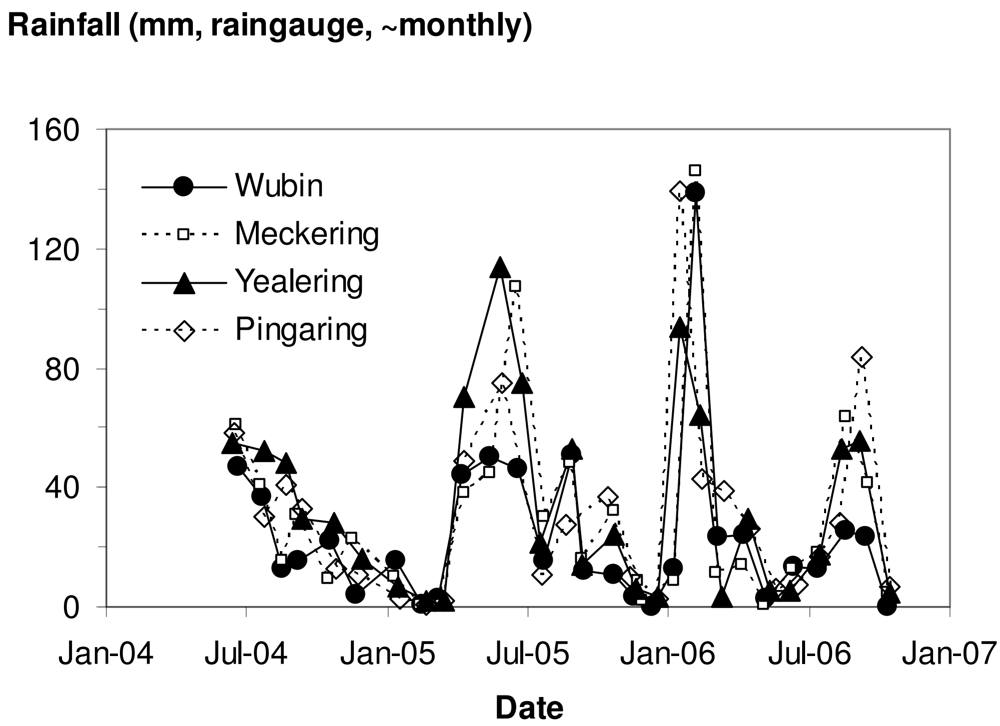

Figure 3. Rainfall (approximately monthly) measured with rain-gauges at each site.

Landscape conditions

Depth to water-table. Figure 4 shows the variation with time in average depth to water-table. Median values for the period Jan 2004 to October 2006 were: 0.8 m (Meckering), 0.9 m (Yealering), 1.2 m (Pingaring) and 2.1 m (Wubin). Water-tables fluctuated seasonally, but site averages were within 0.2–0.5 m of the median 80% of the time. The sharpest rises in water-table were at Pingaring and Wubin when water-tables rose by ~1.0 m following the high rainfall event of Jan/Feb 2006 (Figure 4).

Relationship between ECe and depth of the water-table. At the outset of the trials, we hoped that each site would display independent variation in the severity of both salinity and waterlogging. In the event the two factors tended to be correlated. For example, Figure 5 shows the link between EC_e and water-table depth in June 2004 at the four sites. It is clear that the only site that displayed winter waterlogging would have been Meckering, and at this site EC_e values were relatively low (less than 20 dS/m) until water-tables became shallower than 0.4 m; at depths less than 0.4 m, EC_e values increased to 100 dS/m or more (Figure 5). At the other three sites, the water-tables varied between 0.9 and 1.3 m (Yealering), 1.0 and 1.3 m (Pingaring) and 1.7 and 2.3 m (Wubin) and ECe values were all less than 35 dS/m).

Figure 6 shows the relationship between average water-table depth and average salinity of the groundwater for the four sites. At three of the four sites, the salinity of the groundwater was at least partly related to water-table depth (Figure 6). Linear correlations between depth of the water-table and salinity of the groundwater were significant at Pingaring ($P < 0.05$) and provided single outlying points were removed, also significant at Wubin ($P < 0.01$) and Meckering ($P < 0.05$).

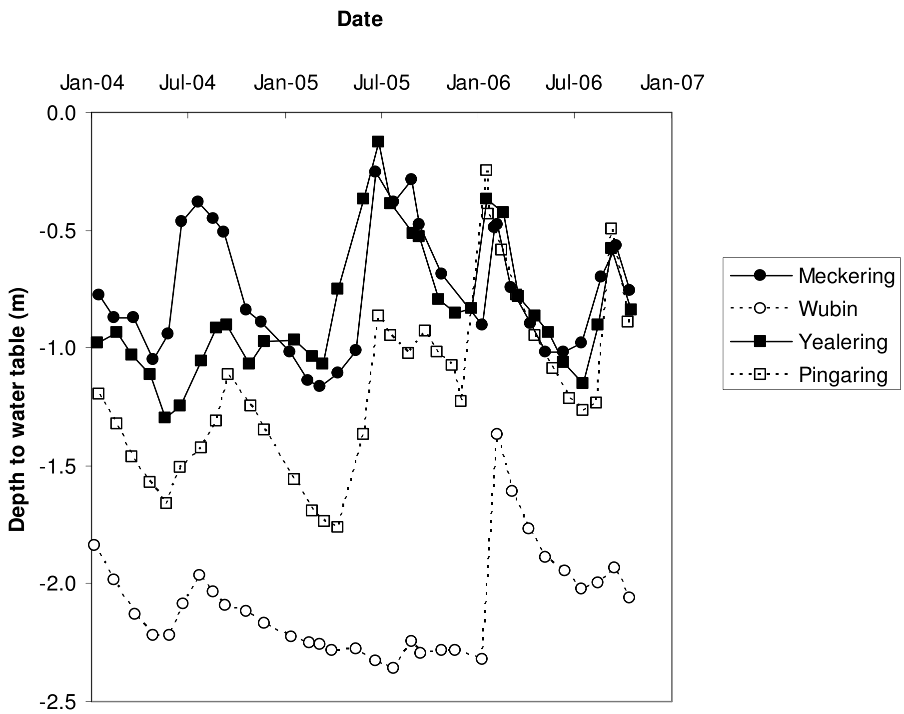

Figure 4. Average depth of the water-table at the four Transect sites. Average salinities of the groundwater were: Meckering 19.5 dS/m (range 13.9 – 40.6 dS/m); Wubin, 46.4 dS/m (range 27.6 – 55.4 dS/m); Yealering, 30.2 dS/m (range 25.6 – 34.8 dS/m) and Pingaring 43.4 dS/m (25.3 – 62.1 dS/m).

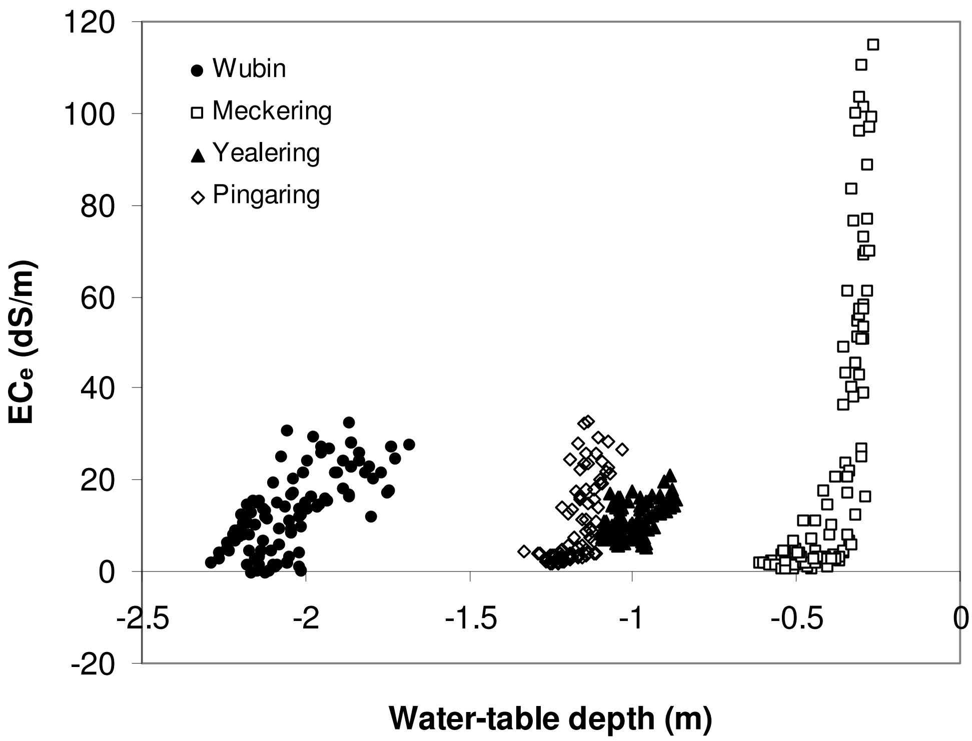

Figure 5. Relationship between depth to the water-table in June 2004 and the EC_e (0-50 cm). Each point is the mean for a 5 x 5 m cell on the plots. EC_e data were determined from calibrated EM38 surveys. Water-table values were krigged from the bore data as described in the Materials and Methods.

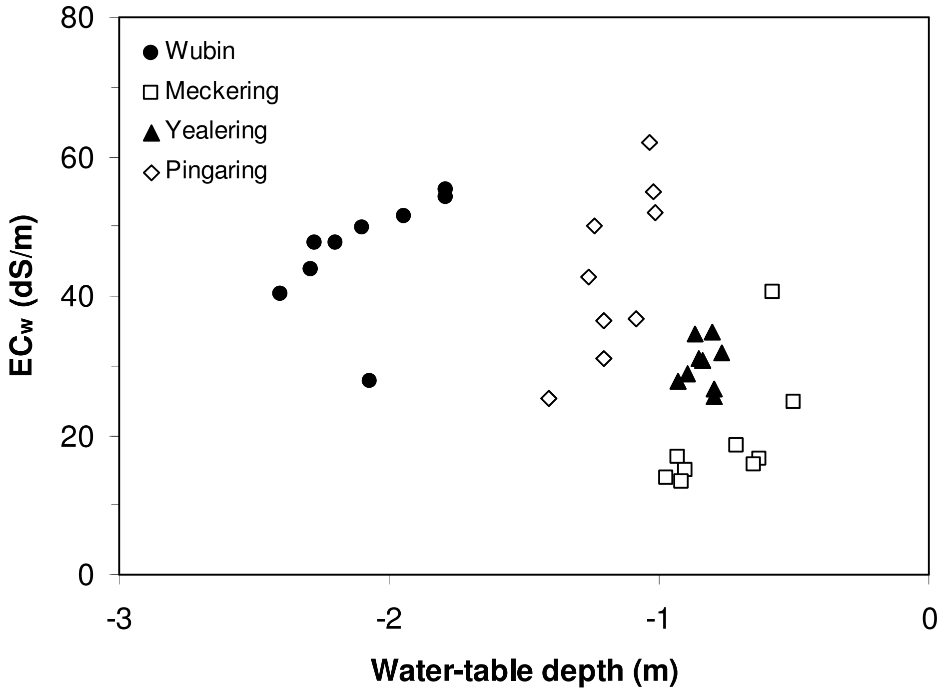

Figure 6. Relationship between average depth of the water-table over the life of the experiment and salinity (EC_w values) of the groundwater. Water-tables were measured at approximately monthly intervals for 32 months. Salinity was measured in summer and winter on 5 occasions.

Plant survival

The survival scores for each species/site are given in Figure 7, and the main trends are summarised in Table 1. In the summary survival is reported over the 1st phase (spring '03 to winter '04) or the 2nd phase (winter '04 to autumn '06) of the trials. Average survival across sites in the 2nd phase decreased in the order Yealering (76%) > Meckering (47%) ≈ Pingaring (43%) ≈ Wubin (40%) (Table 1).

Table 1. Summary of the percent survival of the six perennial species planted at each site. The dates mark the end of the 1st and 2nd phases of the experiment respectively.

Date assessed	Saltbush	Bluebush	Rhodes grass	Salt water couch	Samphire	Lucerne	Average
Meckering							
21-Jun-04	86	70	62	68	42	40	61
10-Apr-06	80	62	48	66	22	2	47
Wubin							
22-Jun-04	98	92	4	2	0	0	33
11-Apr-06	100	92	26	16	0	4	40
Yealering							
20-May-04	100	100	100	94	38	90	87
18-Apr-06	100	100	80	54	38	84	76
Pingaring							
27-Jul-04	92	94	26	48	6	4	45

19-Apr-06	98	96	12	10	10	30	43

There were two major periods of mortality: 44% of all plants died in the six months between November 2002 and May 2003 (ie. the end of phase 1). These plants were therefore all replaced in July/August 2003. Following this, another 43% of plants died in the six months to January 2004 (calculated from data in Figure 7). Mortality rates then became much more stable and only a further 11% of plants died in the next 16 months to May 2006.

A spatial analysis was conducted to relate plant performance by May 2003 and January 2004 to prior site conditions, that is soil salinity and the depth to watertable 5-6 months earlier (Figures 8 and 9). In these figures plant performance was related to EC_e values over the upper 50 cm of the soil profile because this seemed a reasonable interval given the deep-rooted nature of these perennial species.

The four sites studied here encompassed a total range of EC_e values (to 70 dS/m in the late spring of 2003 and to 110 dS/m in the winter of 2004) and a total range of depths to the water-table (to 2.2 m in January 2004 and to 2.3 m in June 2004). The total range of options in which plants could survive was therefore 70 x 2.2 = 154 dS in Figure 8, and 110 x 2.3 = 253 dS in Figure 9.

An "adaptation score" was derived by calculating the proportion of the product of salinity range x water-table depth range that the surviving plants occupied. For example, Figure 8 shows that river saltbush plants survived between EC_e values of 0.44 and 57.7 dS/m and depths to water-table of 0.7 and 2.2 m. These plants therefore occupied (57.7 - 0.44) x (2.2 - 0.7)/154 x 100 = 56% of the total range of EC_e x water-table depths possible in Figure 8a. "Adaptation scores" have been calculated in a similar way for all the other species tested in Tables 2 and 3.

Plants were ranked for best growth ("shoot volume" or "shoot surface area") across sites and those plots that contained the 10% largest plants were separately marked in Figures 8 and 9. Not surprisingly, Tables 2 and 3 show that the plants grew well over a narrower range of salinities and depths to water-table than the ranges over which they survived.

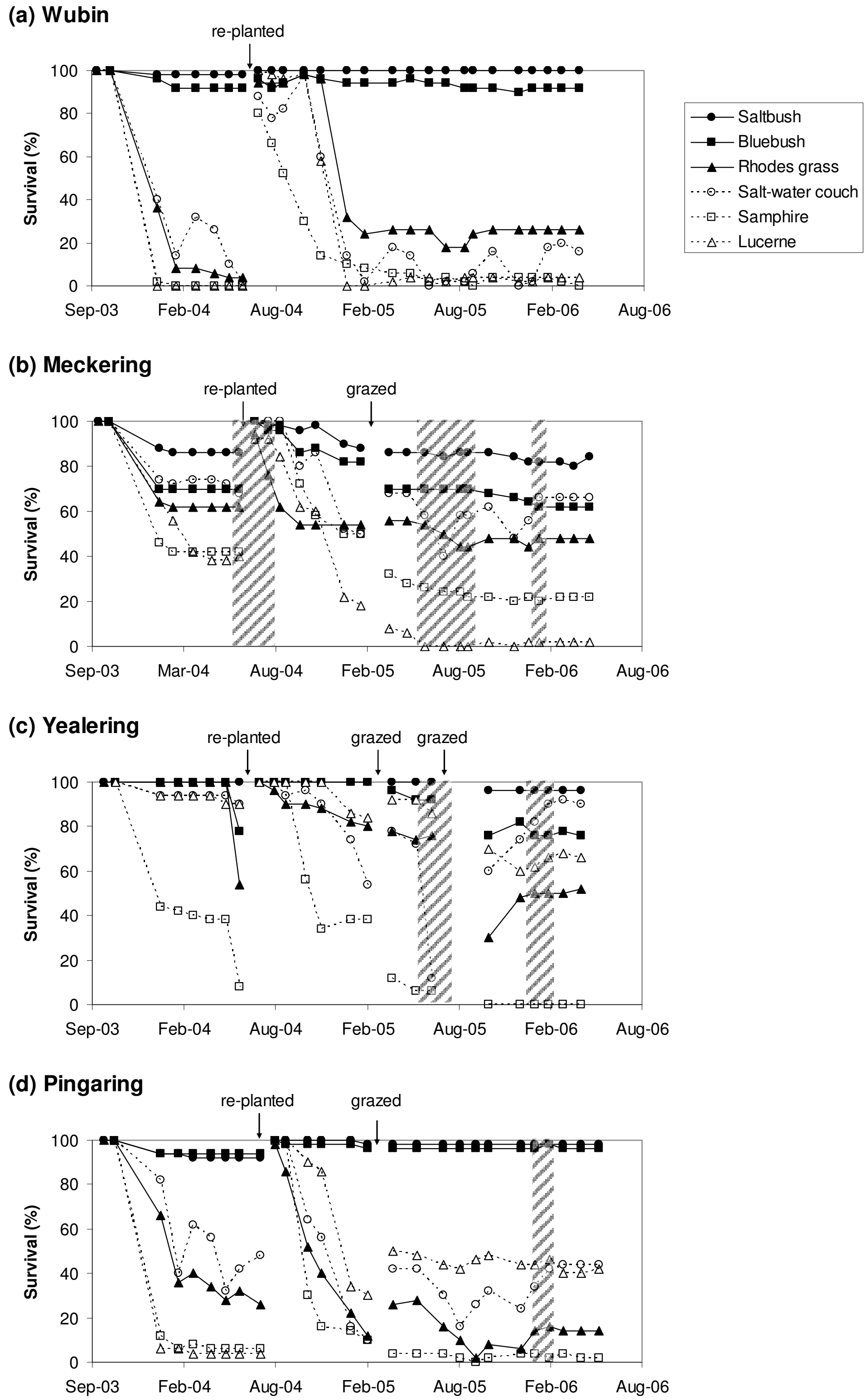

Figure 7. Survival of the six species at: (a) Wubin, (b) Meckering, (c) Yealering, and (d) Pingaring. The hatching denotes periods of waterlogging when the average depth of water-table was less than 0.5 m. Note the apparent changes in survival (resurrection?) of salt water couch were due to difficulties in accurately scoring survival of this species in winter.

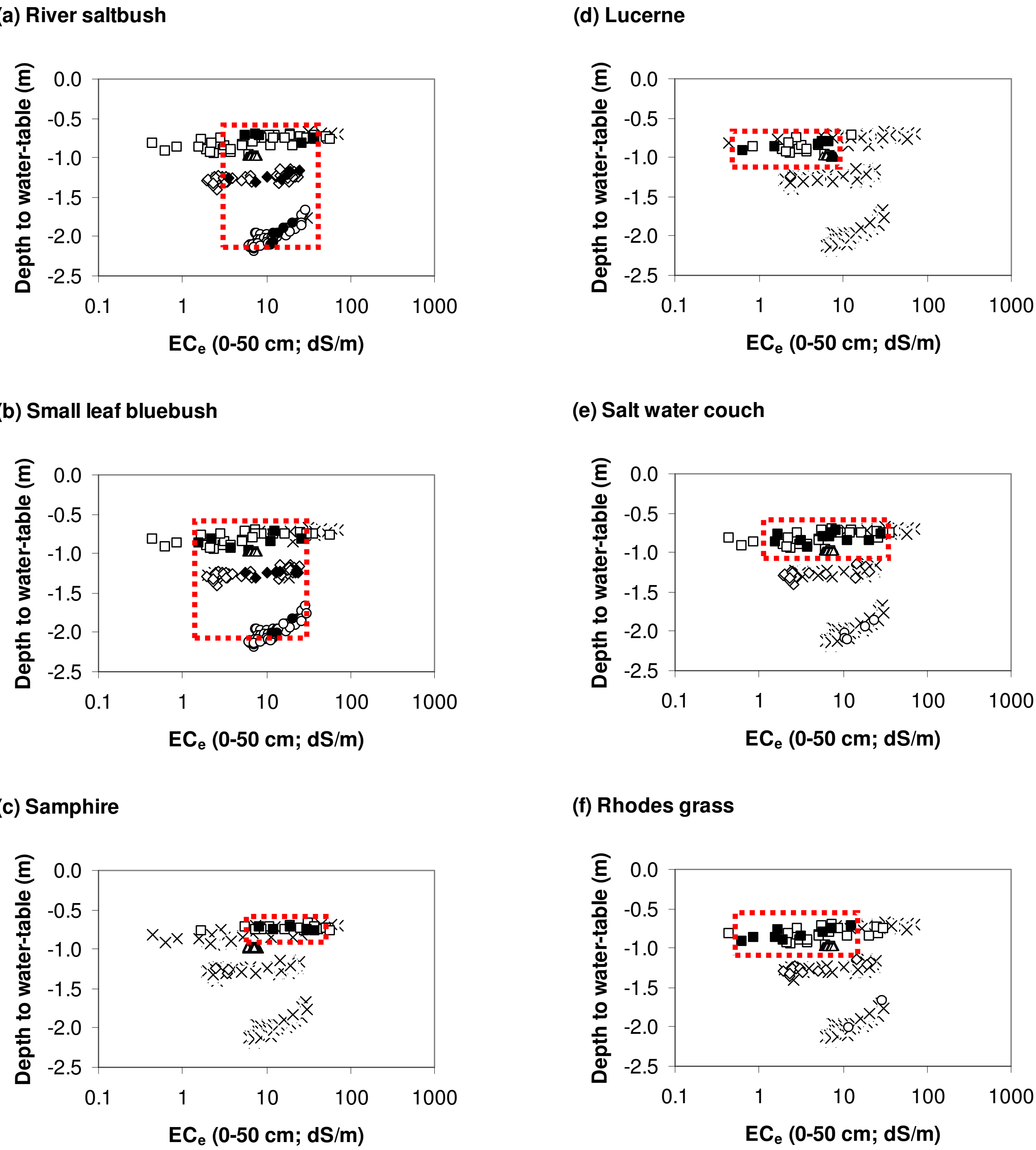

Figure 8. Ecological zonation after the summer of 2003/04: effects of soil EC_e (0-50 cm) and depth to water-table on the location of plants that died (crosses), plants that survived (open symbols) or the largest 10% of surviving plants (black symbols). The dotted square encompasses the black symbols. Circles = Wubin; squares = Meckering; triangles = Yealering; diamonds = Pingaring. Plant survival and growth were scored in May 2004 and related to the depth to the water-table in January 2004 and the EC_e measured in November 2003. EC_e data were determined from a calibrated EM38 survey. Water-table values were krigged from the bore data as described in the Materials and Methods except for the Yealering data, where a significant krigging process could not be established.

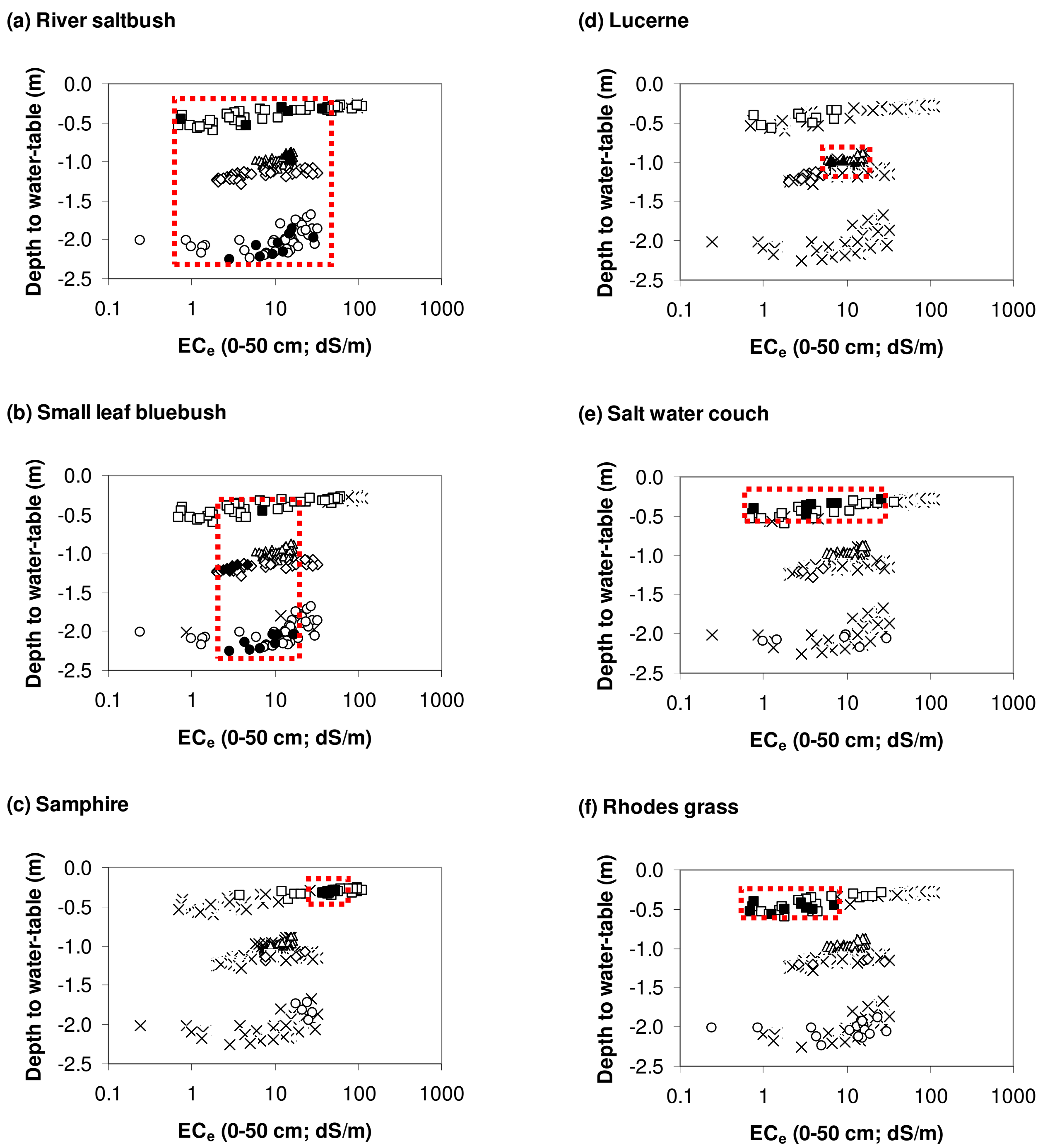
(a) River saltbush
(b) Small leaf bluebush
(c) Samphire
(d) Lucerne
(e) Salt water couch
(f) Rhodes grass
Depth to water-table (m)
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
0.1
1
10
100
1000
EC$_e$ (0-50 cm; dS/m)

Figure 9. Ecological zonation after the winter of 2004: effects of soil EC_e (0-50 cm) and depth to water-table on the location of plants that died (crosses), plants that survived (white symbols) or the largest 10% of surviving plants (black symbols). The dotted square encompasses the black symbols. Circles = Wubin; squares = Meckering; triangles = Yealering; diamonds = Pingaring. Plant survival and growth was scored in January 2005 and related to the depth to the water-table in June 2004 and the EC_e measured in June 2004. EC_e data were determined from a calibrated EM38 survey. Water-table values were krigged from the bore data as described in the Materials and Methods.

Table 2. Summer 2003/04: ranges of ECe and water-table depth, and adaptation score associated with: (a) plant survival, and (b) best growth of the six test species. Adaptation scores were calculated as detailed in the Discussion.

A. Survival

Species	EC_e (dS/m) range	Water-table depth (m) range	Adaptation score (%)
Samphire	1.7 – 57.7	0.7 – 1.3	23
River saltbush	0.4 – 57.7	0.7 – 2.2	56
Small leaf bluebush	0.4 – 57.7	0.7 – 2.2	56
Salt water couch	0.4 – 36.6	0.7 – 2.1	33
Rhodes grass	0.4 – 30.2	0.7 – 2.0	25
Lucerne	0.6 – 8.0	0.7 – 1.2	2

B. Best growth

Species	EC_e (dS/m) range	Water-table depth (m) range	Adaptation score (%)
Samphire	8.2 – 37.6	0.7 – 0.8	1
River saltbush	3.5 – 36.6	0.7 – 2.1	30
Small leaf bluebush	1.5 – 26.2	0.7 – 2.0	21
Salt water couch	1.5 – 28.1	0.7 – 0.9	4
Rhodes grass	0.6 -12.8	0.8 – 0.9	1
Lucerne	0.6 – 7.4	0.8 – 1.0	1

Table 3. Winter 2004: ranges of ECe and water-table depth, and adaptation score associated with: (a) plant survival, and (b) best growth of the six test species. Adaptation scores were calculated as detailed in the Discussion.

A. Survival

Species	EC_e (dS/m) range	Water-table depth (m) range	Adaptation score (%)

Samphire	3.8 – 110	0.3 – 1.9	71
River saltbush	0.2 – 110	0.3 – 2.3	87
Small leaf bluebush	0.2 – 61	0.3 – 2.3	48
Salt water couch	0.7 – 38	0.3 – 2.2	27
Rhodes grass	0.2 – 30	0.3 – 2.2	23
Lucerne	0.8 – 17	0.3 – 1.3	6

B. Best growth

Species	EC_e (dS/m) range	Water-table depth (m) range	Adaptation score (%)
Samphire	38 – 54	0.3 – 0.4	>1
River saltbush	0.8 – 38	0.3 – 2.3	29
Small leaf bluebush	2.4 – 17	0.5 – 2.3	11
Salt water couch	0.8 – 27	0.3 – 0.5	2
Rhodes grass	0.7 – 7.2	0.4 – 0.6	>1
Lucerne	6.5 – 12	1.0 – 1.1	>1

Discussion

Breadth of adaptation

Farmers seeking to establish saltland pastures need a method for minimising the risk associated with revegetation. One of the key findings of this paper is that plants vary in their adaptation to combinations of salinity and depth to the water-table.

In terms of ability to survive the range of salinities and depths to the water-table encountered in the present study, river saltbush was clearly superior: it survived over a wider range of salinities and water-table depths than any other species tested (adaptation scores 56 and 87%; Tables 2 and 3). Also highly adapted were small leaf bluebush (adaptation scores 56 and 48%) and samphire (adaptation scores 23, 71%). All other species tested were more specific in their site requirements.

In terms of broadacre farming – the lowest risk strategy would clearly be to establish the plants with the largest adaptation score – river saltbush, small leaf bluebush and samphire as recommended by other authors (cf. Malcolm and Swaan, 1989.). However, adopting this strategy can lower the financial gains possible from saltland sites of higher productive potential value. What we require is a means of clearly focusing attention in the saltland of greater capability.

There is one qualification that needs to be made about choice of sites in the current work. Although many sites covered a range of salinities, in general there was a limited range of water-table depths within sites, and the bulk of the shallow water-table readings in Figures 8 and 9 were from Meckering. Therefore there is a risk that the effects of shallow water-tables in the current study are confounded by site, and our conclusions certainly need to be tested against a wider range of sites.

Tolerance to salinity and waterlogging

This section considers the effects of high salinity and shallow water-tables as constraints to rapid plant growth. The information presented here suggests that of the species tested, samphire has high growth at the highest salinity and tolerance to salinity decreased in the order: samphire > river saltbush > salt water couch > small leaf bluebush > rhodes grass ≈ lucerne (Table 4). Samphire also had high growth at the shallowest water-tables, and tolerance to shallow water-tables decreased in the order: samphire ≈ river saltbush ≈ salt water couch > small leaf bluebush ≈ rhodes grass > lucerne (Table 4).

Data are available in the literature on the relationship between shoot biomass production and salinity in nutrient solutions or irrigated sand cultures for five of the species we tested, and it is interesting to see that the EC_w associated with a 50% decrease in shoot growth from the literature was similar to upper limit of the EC_e range for good growth (Table 4). This is encouraging as hydroponic data are now available for several hundred plant species and our empirical relating of EC_w and EC_e values suggests that the likely adaptation of these plants to soils of different salinity can now be estimated.

Table 4. Upper ECe and shallowest water-table depth allowing good growth (from Figures 8 and 9) and the relationship between published ECw figures for a 50% decrease in growth.

Species	Upper ECe (dS/m) for good growth	Shallowest water-table depth (m) for good growth	ECw (dS/m) for 50% decrease in growth	Reference
Samphire	38, 54	0.7, 0.3	60	Short and Colmer (1999)
River saltbush	37, 38	0.7, 0.3	40	Aslam *et al.* (1986)
Salt water couch	28, 27	0.7, 0.3	18-29	Dudeck and Peacock (1985)
Small leaf bluebush	26, 17	0.7, 0.5	NA	
Rhodes grass	13, 7	0.8, 0.4	10-15	Maas (1986)
Lucerne	7, 12	0.8,1.0	9	Maas (1986)

The data from the present study suggests that the location of bluebush in the matrix overlaps that of saltbush to a far greater extent than was previously appreciated. Ecological zonation occurs on saltland between river saltbush and small leaf bluebush and the previous literature on this subject attributed this primarily to a presumed greater sensitivity of small leaf bluebush to waterlogging

(Malcolm and Swaan, 1989). Contrary to this view, our data appears to suggest that river saltbush and small leaf bluebush differ mostly in their salt tolerance. They survived and had highest growth over water-tables of very similar ranges. There is a clear need for further work to be conducted under controlled conditions to elucidate the causes of zonation involving small leaf bluebush. One approach that could be useful would be to compare the salt and waterlogging tolerance of small leaf bluebush and its current nearest neighbours in the salt/waterlogging matrix – saltbush and tall wheat grass (cf. Figure 1).

Recent work focusing on the causes of ecological zonation between puccinellia and tall wheat grass could serve as a model for these experiments. For many years, it was widely believed (on the basis of field evidence) that puccinellia was more salt tolerant than tall wheat grass (Runciman 1986, Malcolm 1986, Lay 1990, Barrett-Lennard and Malcolm, 1995). However doubts about the veracity of this claim persisted, and in a series of experiments under controlled conditions, Jenkins (2007) showed that the causes for the differences in ecological zonation were due to differences in waterlogging tolerance under saline conditions. Both puccinellia and tall wheat grass had similar growth responses to salinity under drained conditions. However puccinellia had 60–120% *increases* in shoot dry weights under saline (100–250 mM NaCl) waterlogged compared with saline drained conditions, whereas tall wheat grass had 75–88% decreases in shoot dry weights under similar conditions. Experiments in nutrient solution culture showed that puccinellia was remarkably adapted to saline/hypoxic conditions with strong maintenance of K^+/Na^+ ratios in shoots, a doubling of root cortical cross sectional area, a 60% increase in root porosity, the generation of a strong barrier to radial oxygen loss from the roots, the development of a more porous cubic cell packing in the cortex, and an increase in the suberisation of the hypodermis, endodermis and xylem (Jenkins 2007).

Site diagnosis for land capability assessment

EM38 readings (termed EC_a values) reflect the bulk electrical conductivity of the soil, and this is affected by soil salinity, soil texture and soil moisture. One factor which would greatly accelerate site diagnosis for land capability assessment would be an ability to use raw EM38 data to estimate salinity (EC_e values) without the necessity of establishing EC_a/EC_e calibration curves. We have previously noted that soil profiles on saltland are continuously wetted by the shallow water-tables (Barrett-Lennard and Altman, 2007). It might therefore be possible to obtain reasonable estimates of the bulk conductivity of the soil over depths like 50 cm knowing EC_a values and the soil's texture and the depth of the water-table. We will examine this possibility further using the combined datasets from the WA2 SGSL project.

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