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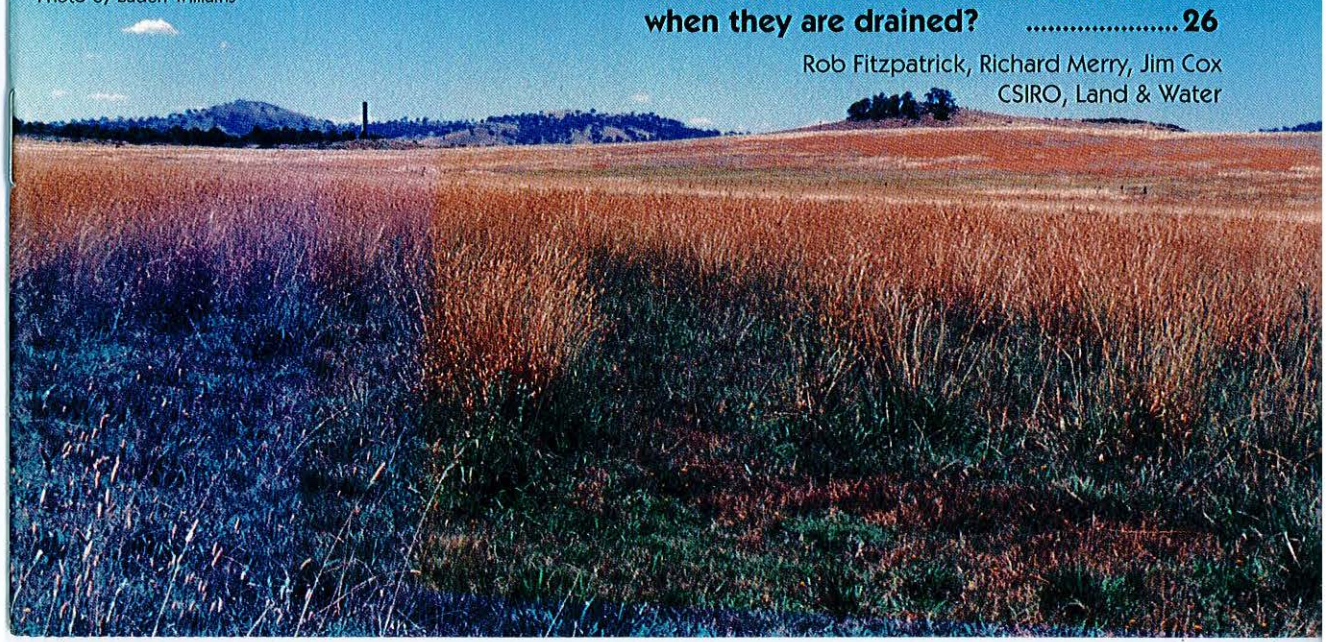
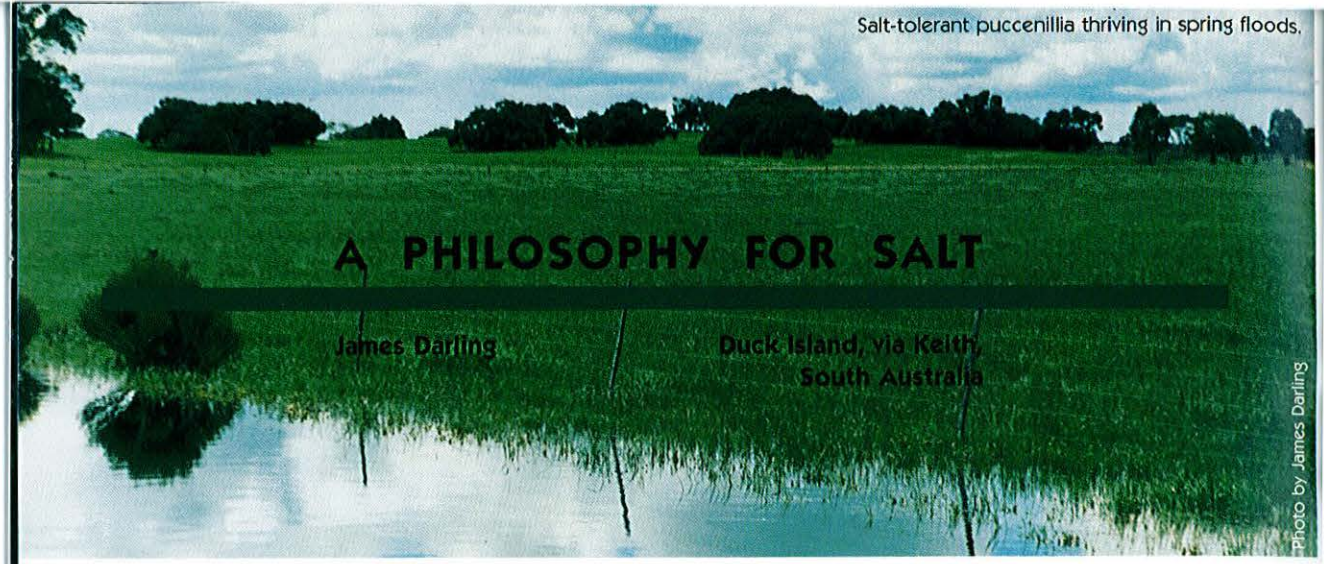
Salt damage on River Murray floodplain, South Australia.

Photo by Peter Taylor

Crace Park discharge area, ACT.
Photo by Baden Williams





Salt-tolerant puccenillia thriving in spring floods.

Photo by James Darling

A PHILOSOPHY FOR SALT

James Darling

Duck Island, via Keith,
South Australia

The title I was given was 'A Philosophy for Saltland Agriculture'. The more I thought and wrote about salt in the Australian landscape, it was obvious it was the same salt whether it was in the bush or associated with agricultural land or indeed in towns or cities. Salt is something all inhabitants of this continent share in common. Consequently, this editorial comment is simply titled 'A Philosophy for Salt'.

The Australian landscape suffers from inadequate description. We have not understood landscape processes and we have not given due place and due regard to the make-up, the components, of our many and varied landscapes. Those who do comprehend these processes are yet to find a language that expresses that awareness and makes it available to all Australians.

The highest priority in terms of environmental and educational need is an understanding of watertable management. The component of the Australian landscape that has been most disregarded is salt. The two are inextricably linked.

Nature is never a background.

I had a quintessential experience sitting on a hay bale outside Charters Towers in the Queensland sun listening to a CSIRO hydrogeologist say that 150 kms in from the Australian coast meant that 6–8 kg of salt per hectare per year would be deposited out of the atmosphere. The next step was to multiply the annual salt deposit by geological age to estimate the staggering salt loads which exist in our landscape.

But even more revealing was the fact that, in the native vegetation and the regrowth of the Upper Burdekin, there was little or no evidence of salt.

The scientific message to the land managers of that region was simple: if you continue the present land management practices, the massive concentrations of salt—like a sleeping giant—would awake, become activated salt: salinity—as sure as night followed day.

There are, of course, many regions of this continent with significant areas of salinisation which are stark and obvious: widening bare scalds, dying vegetation. Salt is seen as a corrupter and destroyer, crossing state boundaries, poisoning in highly-mobile concentrations.

But it is not shock and impact and scare mongering that is required, but rather education, understanding and informed action. We need to increase our knowledge base. We need more hydrologists, hydrogeologists and expertise in the landscape processes of this continent. And we need to make available to the Australian community how this continent evolved to deal with itself.

The clue to the long-term health of this land is the dynamic equilibrium of watertable management. When you deal with the dynamics of watertable management, you must take into account the air, the trees, the plants, the ground, as well as what happens in and under the ground.

The whole of the Australian landscape can be viewed as a series of dynamic balances. Salinity—activated salt—is almost invariably the indicator of a watertable which is seriously out of balance.

The giant is awakening, stretching, having one elbow scratched. He is a massive creature. What we must do entails landscape-scale challenges and landscape-scale opportunities.

The giant must be cooled, calmed, shaded, his limbs must be deactivated, bedded-down, reduced to minimum impact.

It was the job of the PUR$L conference to provide the vision, the intelligence, the energy and the methods to undertake this task. The health of our continent demands it.

DRYLAND SALINITY RESEARCH

approaching the truth

Alex Campbell **National Dryland Salinity Program**

Research into dryland salinity brings us ever closer to the truth. Unfortunately the message is often disturbing, particularly the predictions of areas at risk of future salinisation and the realisation that current farming practices will be ineffective in arresting, let alone reversing this trend.

But as one door closes another opens.

The second phase of the National Dryland Salinity Program (NDSP) recognises that the size of the problem nationally will force some hard decisions: decisions about where limited public resources for salinity management need to focus on prevention, where they need to focus on rehabilitation and where they need to focus on living with salt.

The PUR$L community has long been a driving force behind the search for a way to live with salt, not just as a survival strategy but also as an opportunity arising out of adversity.

The 1999 biennial PUR$L conference held at Naracoorte in South Australia brought together international and national specialists to reveal the most recent developments in ways to live with salt. As it always does, the full richness of this conference emerged with the interaction between presenters and the audience that included extension providers, policy makers and land managers.

This conference continued the trend which sees the PUR$L agenda ever broadening as new stakeholders emerge with an interest in salinity. Although the impact on agriculture is still central, increasingly conservationists, local government and water resource managers are recognising salinity issues they cannot avoid.

Experience has shown that understanding the biophysical processes leading to salinity and having the tools to manage it do not always lead to the implementation of adequate management practices. The key drivers of change (e.g. market forces) are often absent and key inhibiters (e.g. social values and uncertainty, inconsistent policies and regulations at different levels of government) are often present. One of the critical issues for salinity management will be institutional support and PUR$L, with its emphasis on 'productive use', will continue to play a key role in encouraging the uptake of technically feasible, practical and financially attractive solutions.

The Australian Association of Natural Resource Management support of the conference culminates in this special edition of *Natural Resource Management*— an edition that brings together a selection of key papers highlighting the breadth of approaches to living with salinity.

Photo by Bruce Munday

NEW HORIZONS IN THE USE OF SALINE RESOURCES

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Abstract

Saline soils, so often the result of landscape mismanagement, present great challenges to environmental managers and agricultural producers. This paper demonstrates that great opportunities also arise from salinity research. It reviews the agronomic potential of some halophyte crops and forage plants and explores the contribution they can make to remediation or improvement of some salt-affected soils and ecosystems through the rhizocanicular effect, halodecking and bio-remediation. The paper also discusses the opportunities for water desalinisation using capacitative deionisation technology.

Key words

Salinity, halophyte, water quality, bio-remediation, desalination

Introduction

The majority (90 %) of saline soils in the world are created by natural processes (primary salinisation); less than 10 % is due to human activity (secondary salinisation). Yet, one third to one half of irrigated lands are salt affected. Hence, billions of dollars are lost each year to salt. These salty areas should be regarded not as problems, but as opportunities.

Innovative salt technology for sustainability is a 'rapidly rising new sun' on the horizon of our salty resources. In the last 30 years the envelope has also been pushed for conventional glycophytes (plants with decreasing productivity with increasing salt levels). Soil amendment and management—along with drainage management—have saved hundreds of thousands of hectares across the world, while some new salt-resisting glycophytes have a more gradual productivity decrease with increasing salinity. There has also been an increased use of miohalophytes (plants that maintain their productivity up to some salt level and then have decreasing productivity with increasing salt levels). Contemporarily, there has been interest in the development of halophytes (plants capable of completing their life cycle under highly salty conditions). Of the halophytic plants the most interesting new crops are the true halophytes or euhalophytes (plants that have increased productivity with increasing salt levels). Euhalophytes are salt-loving (halophilic) and grow *better* under salty conditions than under fresh water conditions. The advantage of halophilic crops is that high salt levels, impermeable soils, and waterlogging can actually improve their productivity. At present, a whole spectrum of salt-tolerant and halophilic crops are being developed. Involved in the development of these new halophilic crops is the relatively new science of salt plants (halophytology) and a new wave of high-salt cultivation (haloculture).

First halophyte patents

The first patented halophilic crop, a cereal grain (NyPa® Grain, *Distichlis palmeri* var. *yensen-1a*), was developed and patented in 1985, followed in 1994 by a patented euhalophyte forage crop (NyPa® Forage, *Distichlis spicata* var. *yensen-4a*). Both crops have optimal growth in warm arid climates (Yensen 1988, Yensen et al. 1995a). While selection and use of halophytes extends from pre-historic times, these halophilic crops were uniquely bred and selected to have new agronomic characteristics, noting that wild or previously domesticated cultivars are not patentable.

NyPa Forage

NyPa Forage is the result of more than 20 years of research on salt-tolerant grasses and the breeding and selection of thousands of varieties and populations from around the world.

The productivity of NyPa Forage is several times that of the typical saltgrass, with the results of one trial shown in Table 1.

Productivity-salt level trials conducted at the University of Arizona (Yensen et al. 1998), the US Salinity

Saltgrass variety	NyPa Forage	*Distichlis* 1	*Distichlis* 2	*Distichlis* 3	*Distichlis* 4	*Distichlis* 5
t/ha/4 months	13.9 ± 3.5	1.6 ± 0.4	1.3 ± 0.3	0.6 ± 0.1	0.7 ± 0.2	0.5 ± 0.1

Table 1. The above-ground, harvestable, dry-weight biomass of NyPa Forage compared with that of five varieties of *Distichlis* (Yensen et al. 1998)

Laboratory (Shannon & Grieve, unpubl.), Agriculture WA (Prefumo & Barrett-Lennard, unpubl.) and Latrobe University (Sargeant, unpubl.) have observed very different growth curves over salinity levels. It is not known if this variability is the result of differing light levels, temperatures, humidities, mycorrhizae and/or salt-ion. Typically, under high light and temperature the optimal salinity is between 20–30 dS/m. The new variety will grow at full strength sea water (~ 46 dS/m).

Recent trials in various countries suggest that under proper management and cultivation the forage variety can be suitable for goats, sheep, and beef cattle. Yearling dairy calves grew almost as well (1 kg/day/4 kg feed, Yensen 1997) with a NyPa Forage-formulated diet as with a conventional-formulated diet.

Halophyte crops

Salt-tolerant crops in various stages of use and development include: *Atriplex, Salicornia,* some *Eucalyptus,* some *Casuarina, NyPa, Kosteletzkya, Juncus, Kochia, Pandanus, Suaeda, Tamarix* and *Zostera. Acacia, Batis, Chloris, Coccoloba, Cressa, Crithmum, Grindelia, Leptochloa, Limonium, Prosopis* and *Sporobolus* may also become potential crops (Yensen & Bedell 1993). To assist in the selection of appropriate crops for different regions a prototype computer program has been developed with the assistance of the Food and Agriculture Organization of the United Nations.

Serial biological concentration

An entire community's food, shelter, fuel and ornamentals can all be generated from serial haloculture of the different crops. After each haloculture the effluent/drainage waters can be reapplied to the next halophilic crop. Due to evapotranspiration in an 'open' system each crop in the series must be increasingly more salt-tolerant in a serial biological concentration system (SBC). The last crops are brine-loving species (*Artemia* spp., *Spirolina salina, Dunniella* spp., *Halobacter* spp., *Halomonas* spp.).

A small-pilot SBC system might utilise 50–100 m^3/ha of water per day at 10 000–15 000 ppm (15–20 dS/m) on a miohalophyte. The second level might utilise 25–50 m^3/half-ha/day at 30 000 ppm (nearly sea water). The third level might utilise 10–25 m^3/quarter-ha/day at 60 000 ppm (hypersaline) on a euhalophyte crop, however the known hypersaline crops are limited.

Halophyte contribution to improvement of salt-affected soils and ecosystems

Rhizocanicular effect

New understanding is being gained from an old phenomenon, the opening of soil via the 'rhizocanicular effect' (or root channels). The rhizocanicular effect permits percolation of water in otherwise impermeable soils (Yensen et al. 1995b). Thus, the old adage that 'adding salt water to a clay soil will ruin the soil' is not always true. Heavy, clay, alkaline soils have been irrigated with salty water (from 15–46 dS/m depending on site) to grow halophyte crops. Strong rhizocanicular halophytes can allow water drainage and movement of salts down and out of the upper soil system.

Halophytes with rhizocanicular action typically have sharply-pointed rhizomes (called 'pene-rhizomes' for their penetration ability). They can penetrate heavy deflocculated clay soils, hardpan, caliche, asphalt, and brick-like clays.

Rhizocaniculated soils have improved soil structure and in some cases the obligate halophyte crops were *unable to grow* due to *lack of salt.* To understand this, consider that salty soils can lose their clumped (flocculated) structure because the salt ions cause the soil particles to repel each other (deflocculate) resulting in any remaining pores becoming clogged with colloidal clay particles. Organic matter can have a beneficial effect by helping to re-establish soil structure (Lebron, pers. comm.), but mulch is ephemeral and oxidises into carbon dioxide, water and by-products. In contrast, halophytes with a rhizocanicular effect provide a persistent sustainable 'growing improvement' to the soil.

Protein	Gross fat	Non-nitrogenous matter (by difference)	Gross fibre/cellulose	Ash	Energy	Lignin
6–19%	8%	47%	20–37 %	5–14 %	1245 kJ/100g	5–7 %

Ca	P	K	Mg	S	Na
0.2–0.9 %	0.1–1.0 %	0.7–1.2 %	0.14–0.33 %	0.18 – 0.27 %	0.2–2.8 %

Cl	B	Cu	Fe	Mn	Zn
0.8–1.1%	2–5 ppm	4–200 ppm	250–600 ppm	39–75 ppm	30–67 ppm

Table 2. Chemical composition of NyPa Forage (Yensen 1997; Shannon, pers. comm.)

Halodecking

A new understanding is also developing of how halophytic vegetation is capable of growing over salt beds and moving the salt down and/or building up the surface soil matrix. This process causes the salts to be 'bedded down' or halodecked (a salt layer and/or saline soil covered with plant material so that glycophytes can be grown). This process appears to make salts 'inactive' with regard to the local ecosystem and microhabitat (J. Darling, pers. comm.). In the arid Atacama Desert of Chile and Peru metre-thick layers of salt halodecked so that garden vegetables could be grown at the surface have been observed. *Distichlis* sp., a euhalophyte species, had halodecking mats up to 2 m high.

Halophytes have adapted to tolerate many salts (e.g. some gypsophilous halophytes have become specialised in growing on gypsum salts and gypsiferous soils and have become obligate gypsophilous halophytes [Yensen et al. 1999]). Closely related populations can even have widely differing tolerances to the same salts.

Halophyte salt management

Choice of halophyte crop for each field situation depends on the soil–water condition and the way in which the particular halophytes manage salt. Halophytes manage their salt load by exclusion, accumulation and/or excretion.

Exclusion

Excluder plants (e.g. *Hordeum* spp., *Melilotus* spp. and most glycophytes) have salt control at the root level and exclude the salts from entering the vascular system. The exclusion of salt is often an energy-expensive process. For plants to survive under saline conditions it was thought that they must expend energy for salt management. The O'Leary Rule (J. O'Leary pers. comm.) suggests that for every gram molecular weight of salt pumped out of a plant via the sodium pump the plant must expend the energy of one gram molecular weight of adenosine-tri-phosphate. The O'Leary Rule applies for conventional glycophyte plants, an increase in salt level correlating with a direct linear *arithmetic* decrease in productivity.

Halophytes do not appear to follow this rule; they enjoy increased productivity with increased salinity up to an optimal salt level. Above that they begin a curvilinear decrease in productivity.

Accumulation

Accumulator plants (e.g. *Atriplex* spp., *Salicornia* spp.) sequester salts in the cell vacuoles for osmoregulation and to avoid toxic effects. In these plants, salt may account for as much as half the dry weight. While they usually do not make good forages, there are many situations where they are ideal and well-suited (e.g. although under rangeland conditions, deep-rooted plants [e.g. *Atriplex* spp.] can grow well on the fresh rainwater and as such do not accumulate high levels of salt, they can also withstand the salt associated with drought). Some accumulated salts can be toxic (e.g. *Atriplex canescens* growing vigorously on highly-toxic saline soil in Mexico, that had to be fenced off to avoid cattle mortality; Yensen, personal observation). Under other circumstances, however, many *Atriplex* spp. (low in oxalates and malates) can serve as an excellent browse. The selection and development of saltbushes without these liabilities would be an excellent program (Barrett-Lennard & Malcolm 1995).

To reduce leaf–tissue–salt accumulation *Atriplex* spp. have bladder cells (leaf-surface cells which fill with salt, burst with dew and rain and thus excrete salt). This means that they can be grazed after rains when the leaves are most palatable.

Excretion

Excretor plants (e.g. *Distichlis* spp., *Avicennia* spp.) excrete salts through salt glands. Some halophytes excrete salt with bladder cells; others directly excrete salts without salt accumulation making their biomass immediately available as forage.

A beneficial side effect of salt excretion is that the surface salt can eliminate some pests (e.g. aphids coming into contact with salt can be imploded through the osmotic removal of their body fluids [Yensen, personal observation]). Diseases/parasites can also be reduced by adding salts to aquacultural ponds (D.J. Carty, pers. comm.). In general, however, plant problems (e.g. pathogens, insects, overgrazing, weeds, metal accumulation) associated with the cultivation of halophytes are similar to those of conventional crops.

Bio-remediation

Bio-remediation (the removal of toxic salts and compounds with organisms) is a new, rapidly-developing area. While some plants can accumulate the toxic salts directly from the soil, other applications rely on volatilisation and/or precipitation of toxins into harmless compounds by microbes that use halophytes as a carbon energy source. Some macrophytes also can directly bio-remediate certain toxins. Toxic elements, such as chlorine and selenium, can be remediated by volatilisation (Davis, pers. comm., Frankenberger, pers. comm.). Some controversial discussion still exists on the

possibility for reduction of sodium via microbial volatilisation (Maton et al. 1986, Nelidov 1981). However, *phyto-remediation,* by elemental up-take, volatilisation, and precipitation can reclaim toxic waste sites, saline petroleum sludge and mining areas.

Capacitative deionisation technology

Capacitative deionisation technology (CDT), first developed with carbon aerogel at Lawrence Livermore National Laboratory in the USA, can electronically remove dissolved salts and toxic elements. The process (potentially more efficient than Reverse Osmosis or Flash Distillation) is still in the developmental stages, but may soon provide pure drinking water for people and animals (Sheppard et al. 1998).

Carbon aerogel is a new material that can be made from coating carbon felt with a resin which is then pyrolised at high temperature. The resultant carbon aerogel has a density of 0.3–1.0 g/cm^3 (based on 0.13 mm thick material). It has an internal ion-collecting surface area that can be greater than 60 000 times the 'plane form' surface area. The ion-collecting surface area varies from 100–700 m^2/cm^3. Aerogel is a form of carbon with a reticulated structure whose pore size is measured in tens of nanometres. It acts like a 'microscopic sponge'!

Aerogel removes salt ions when an electrostatic potential difference (1.0–1.5 volts) is established on alternating charged sheets of aerogel, as in a capacitor. When salty water passes between the aerogel sheets the positive and negative ions are attracted to their opposite electro-potential and are electro-adsorbed to the aerogel. Particles with a net charge are held to their respective surfaces of the capacitor and later released into a waste stream by removing or reversing the electrostatic charge. The ion-collecting aerogel surface is capable of removing relatively large quantities of salt from a fluid passed between the charged aerogel-sheet electrodes.

Because the aerogel is essentially inert carbon, neither heat, acids nor bases will destroy the CDT electrodes as they would reverse osmosis membranes. The electrodes are stacked and electrically bussed in the shape of a 'flow-through brick'. Bricks are connected in series to meet quality requirements and in parallel to meet volume requirements.

CDT is ideally suited for ultra-pure water production because little energy is lost through the 'non-conductive' water, and large quantities of water may pass through the bricks before the collected salt needs to be electrically flushed. Less than 2 watt-hours/litre are required to purify water with a few hundred parts per million total dissolved salts to less than 100 parts per billion (deionisation only) and the pumping energy is minimal. Ocean water and brine desalinisation is the most difficult for CDT as the electrodes need frequent flushing. However estimated energy requirements are low compared to other technologies:

- CDT process: 5.5 watt-hours/litre
- reverse osmosis: 7.7 watt-hours/litre
- electrodialysis: 17 watt-hours/litre
- thermal evaporation: 600 watt-hours/litre

Salt opportunities and philosophical considerations

Ten percent of the world's land surface is salt affected. Salt-affected soils and ground waters are often natural phenomena that cross national boundaries. The predicted global climate change threatens to increase the world-wide salinity problem. International collaboration and coordination are essential in continued research and in developing regional and global strategies for dealing with salinity issues. In any program, however, it is important to involve from the beginning select farmers and potential beneficiaries, as well as the political and institutional hierarchy. Thus, when the time comes for expansion they already understand the practices necessary.

There has been considerable discussion regarding what programs are most important to fund. Following a 'tongue-in-cheek' philosophy, Yensen's four 'haloculture priority laws' would help society to prioritise its effort and guide its direction in managing salt-driven problems and opportunities:

- *protect the conventional fresh-water crops* (via drainage, soil amendments, appropriate management);
- *develop salt-tolerant conventional varieties* that can tolerate the marginal fresh water areas, as the agro–socio infrastructure already exists for these crops;
- *develop local halophyte species* with natural salt tolerance, as these plants already exist in the regional ecosystem wherein climate adaptation and environmental considerations are minimal; and
- *introduce domesticated halophytes* to the region after careful study and evaluation of their intended and possibly unintended performance.

From an environmental standpoint, the development/introduction of salt-loving crops to replace natural areas rich in a wild species should never be contemplated. Fortunately, there are economic reasons to prevent this as well as the aesthetic ones.

Additional long-term economic reasons exist for preserving species-rich coastal and inland salt marshes.

Besides their natural beauty, the rich diversity can provide future generations with the raw genetic material to develop new halophyte crops.

Humankind has had the habit of salinising an area and then moving on to salinise other areas leaving a trail of 'troubled' land. The technology exists that will allow us to take the salinised land and make it productive again. It may need a different crop and a landowner with a different mind-set, but we no longer have to move on to destroy other lands ... *we have an opportunity.*

The development and use of halophilic crops is only now beginning. Ancient halophyte crops are being re-examined, bred and selected as were the glycophyte crops centuries ago. Of the approximately 10 000 salt-tolerant plants, as many as 250 potential halophyte crops may exist. There is a need for the establishment of salinity research and development centres to generate new crops and technologies and to make these advances widely available.

References

Barrett-Lennard, E.G. & Malcolm, C.V. 1995, *Saltland Pastures in Australia: a practical guide* Bulletin 4312, Department of Agriculture, Western Australia.

Barnett, H., Holmes, J. & Newman, K. 1998, *Microbial Remediation of Saline Soils* EnviRx.

Llerena, V., Alberto, M., Tarin, V. & Ing, M. 1980, 'Una alternativa para integrar a la productividad algunas de las áreas altamente salino-sódico del País', in *Proceedings of The Second Inter-American Conference on Salinity and Water Management Technology*, pp.1–27, Juarez, Mexico, 11–12 December 1980.

Maton, T., Kairusmee. P.,Takahashi E. 1986, 'Salt-induced Damage to Rice Plants and Alleviation Effect of Silicate', *Soil Science and Plant Nutrition*, vol. 32, pp. 295–304.

Nelidov, S.N. 1981, *Effect of Straw on Microbial Activity of Soil and Rice Crop Production,* Dissertation, Candidate of Biological Science, Alma-Ata.

Sargeant, M. 1999, Personal communication and BSc thesis, Latrobe University, Melbourne, Victoria.

Sheppard, C., Yensen, N P. & Vaught, C. 1998, 'Capacitive Deionization (CDI) with Carbon Aerogel: A New Technology for Purifying Contaminated Waters of Salts and Pollutants', *International Workshop regarding Water Quality and Control of Contamination in Latin America,* FAO of the United Nations 30 September–4 October 1998, Arica, Chile

Yensen, N.P. 1997, 'The Agronomic Production and Nutritional Characteristics of NyPa Forage, *Distichlis spicata* var. *yensen-4*, (Poaceae) when grown on highly Saline Water in Arid Regions of the World with respect to Economic Worth', in *International Symposium on Sustainable Management of Salt Affected Soils in the Arid Ecosystem*, ed. A.M. Elgala, p. 363, Ain Shams Univ., Cairo, Egypt, 22–26 September 1997.

Yensen, N.P. 1988, 'Plants for salty soils', *Arid Lands Newsletter,* vol. 27, pp. 3–10.

Yensen, N.P., & Bedell, J.L. 1992, 'Man's Salt Legacy and some Possible Solutions', in *Proceedings of the International Symposium on Strategies for Utilizing Salt Affected Lands, Bangkok*, Thailand, 17–25 February, 1992.

Yensen, N.P. & Bedell, J.L. 1993, 'Consideration for the selection, adaptation, and application of halophyte crops to highly saline desert environments as exemplified by the long-term development of cereal and forage cultivars of *Distichlis spp.* (POACEAE)', in *Toward the rational use of highly salinity tolerant plants*, vol. 2, eds H. Lieth & A. Al Masoom, pp. 305–313, Kluwer Academic Publishers, Netherlands.

Yensen, N.P., Bedell, J.L. & Yensen, S.B. 1995a, 'Domestication of *Distichlis* as a Grain and Forage', in *Biology of Salt Tolerant Plants*, eds M.A. Khan and I.A. Ungar, pp. 388–392, Ohio University, Athens.

Yensen, N.P., Bedell, J.L. & Yensen, S.B. 1995b,'The Use of Agricultural Drain Water for Forage Production in Coastal Ecosystems', in *Proceeding of the International Symposium on Salt-Affected Lagoon Ecosystems,* ed. J. Battle-Sales, Universidad de Valencia, Spain.

Yensen, N.P., Hinchman, R. R., Negri, M. C., Mollock, G. N., Settle, T., Keiffer, C. S., Carty, D. J., Rodgers, B., Martin, R. & Erickson, R. 1999, 'Using Halophytes to Manage Oilfield Saltwater: Disposal by Irrigation/Evapotranspiration and Remediation of Spills', in *Proceedings of the 6th International Petroleum Environmental Conference, Houston, TX, 16-18 November 1999*, The Integrated Petroleum Environmental Consortium, University of Tulsa, Tulsa.

Yensen, N.P., Yensen, S.B. & Weber, C.W. 1988, 'A review of *Distichlis* spp. for production and nutritional values', in *Arid Lands: Today and Tomorrow*, eds E.E. Whitehead, C.F. Hutchinson, B.N. Timmermann & R.B. Varady, pp. 809–822, Belhaven London.

PLANTS IN SALINE ENVIRONMENTS

an Australian experience

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Saltbush in Western Australia.

Photo by Ed Barrett-Lennard

ABSTRACT

Australia faces a substantial and increasing salinity problem. However, saltland is a resource capable of significant production. Australian experience dating back to the 1940s, and especially since the early 1990s, suggests that profitable new agricultural industries can be based around the growth of salt tolerant plants. Realising this potential will require two fundamental changes. There is a need for a renewed commitment to research and development into the capabilities of markets, land and plants. In addition, there needs to be a change in the consciousness of the community regarding the potential of saltland.

KEYWORDS

Halophytes, inundation, land capability assessment, markets, waterlogging

INTRODUCTION

Australia has a major future salinity problem; 2.5 million hectares are presently salt-affected and a total of about 15 million hectares are at risk. Current farming systems appear unlikely to substantially prevent these increases. It is therefore essential to build and develop a capacity for productively using this resource.

Two basic propositions are considered to be true:

- all saltland is potentially productive;
- not all saltland is equally productive.

These statements are based on an understanding of the salt tolerance of plants. Although nearly all crop plants are sensitive to salinity, there is access to salt tolerant plants (halophytes), some of which are able to withstand salt concentrations in excess of those found in sea water.

This paper has three themes:

- Australia's major historical investment in investigations of the tolerance of plants to salinity
- the use of this research as a useful foundation on which to conduct future research;
- the change of heart needed within the broader community (government, research, and farming) as to what is possible with saltland.

HISTORICAL PERSPECTIVE

Historically, Australians have been major innovators in the use of salt-tolerant plants as a means of increasing the productivity of saltland (e.g. the introduction of tall wheat grass and salt water couch in the 1940s [Teakle & Burville 1945], puccinellia in the 1950s [Rogers & Bailey 1963], and halophytic forage shrubs in the 1960s [Malcolm & Clarke 1971]). However, the greatest flowering of research in this area occurred after the establishment of the national program on Productive Use and Rehabilitation of Saline Land (PUR$L) in 1990. The PUR$L group was established as a means of ensuring that technical developments in individual States could be spread throughout Australia.

Since establishment, PUR$L has sponsored six national workshops (at Tatura and Echuca in Victoria, Adelaide and Naracoorte in South Australia, Albany in Western Australia, and Tamworth in New South Wales). Many of the key debates in the field can be traced through the proceedings of these workshops. Three examples are given below.

The role of saltbushes

At the first workshop the Western Australians strongly advocated saltbushes (*Atriplex* spp.) as salt tolerant forages (Malcolm 1990) and participants from South

Australia and Victoria were encouraged to try niche seeding. By the second workshop, the South Australians were able to show good saltbush stands growing on duplex soils in the field, but the Victorians (third workshop) found that saltbushes were not well adapted to clays (Barson 1994). Grazing experiments from Western Australia (also at the third workshop) suggested that saltbushes were only of low nutritive value to sheep (Warren & Casson 1994). However, by the fifth workshop, a change in the role of saltbush was being foreshadowed with emphasis moving towards its capacity as a groundwater pump (Lloyd 1998).

Puccinellia

At the first workshop, Lay (1990) noted that there were responses in the growth of puccinellia to nitrogenous fertilisers. This was confirmed at the second national workshop, where data were presented showing that puccinellia fertilised with split applications of nitrogen had 3 to 4 times the yield of unfertilised plots (McCarthy 1992). At the fourth national workshop Herrmann (1996) noted that gross economic returns from puccinellia of over $200/ha were achievable.

South Australian farmers in the Keith area subsequently formed a successful cooperative to exploit this productivity, marketing puccinellia seed overseas.

The role of trees on saltland

The identification of adapted salt-tolerant trees has been relatively slow—not surprising given the long time required to grow commercial trees. At the first national workshop it was noted that *Eucalyptus occidentalis*, *Melaleuca halmaturorum* and *Casuarina glauca* had great potential (Marcar 1990). After a further eight years it had become clear that 'whilst most species performed best under less saline conditions, *Acacia stenophylla*, *E. occidentalis* and *M. halmaturorum* performed similarly under moderate salinity' (Marcar et al. 1998). The greatest challenge to the use of trees to lower saline watertables occurred at the fourth workshop when Thorburn (1996) noted that 'there is little evidence that trees will take up more water from a watertable than would be lost from the soil if it was bare of vegetation'. Thorburn suggested that accumulation of salt in the root-zone could dramatically affect long-term tree survival and growth.

RESEARCH AND DEVELOPMENT: IMPERATIVES AND OPPORTUNITIES

For saltland industries to flourish, there is a need to understand three capabilities: those of the land, plants and markets. This is seen in terms of three intersecting circles (Figure 1). What is needed is the right plant (or combination of plants) at the right location in the landscape, producing products of greatest commercial value. Realising the potential of salt-affected land for productive use will require a major future commitment to R&D. These three capabilities are a useful framework around which to reassess priorities.

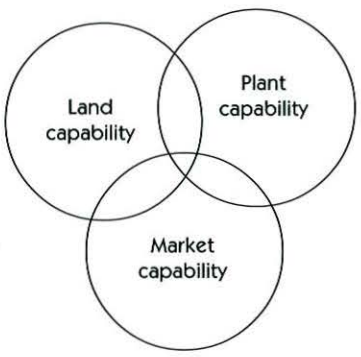


Figure 1. Understanding three capabilities leads to successful industries on saltland.

Defining market capability

There is an urgent need to assess the relative marketability of different saline agricultural options. No such analysis has ever been done for prospective saline agricultural products in Australia or in any other country. This is surprising given that it is the *selling* of products that generates the revenue stream that provides farmers with the incentive to invest in new systems. Farmers will increasingly be able to choose to produce a range of products using saline land. Some of these may be in innovative new industries. The choice of enterprise will be determined by the availability of information about prices, size of market, scale of competition, requirements for transport, and availability of appropriate community infrastructure.

In thinking about market capability, it is essential to be open to possible new saline agricultural products. For example in Western Australia, samphire (*Halosarcia pergranulata*) has been seen as a plant of little value by farmers interested in using it as a source of fodder for grazing animals. However, it can be argued that the approach to this plant has been too blinkered. Samphire partly osmotically adjusts to saline soils using the small molecular weight amino acid glycinebetaine, a compound that can reach concentrations in the tissues of up to 2% dry weight (T. Colmer, pers. comm.). At a

yield of 1 tonne per hectare, this compound could therefore produce a gross revenue stream of about $A1500 per hectare.

Using current knowledge, 26 salt tolerant plant species capable of producing 13 products (or services) of value to agriculture in Australia have been identified (Table 1).

Defining land capability

There is an urgent need to develop techniques for assessing the capability of saltland so that farmers can strategically implement saline agricultural enterprises at optimal locations. At present, land capability surveys generally do not distinguish between different types of saltland.

Ecological zonation in naturally saline environments can give important information about the processes that affect land capability. In Western Australia it has been suggested that saltland should be classified as being of 'low', 'moderate' or 'high' productivity, based on the degree to which it is affected by salinity, waterlogging and inundation (Barrett-Lennard, unpublished).

- *Land of low potential* would have shallow saline groundwater, a high incidence of inundation and (generally) heavy textured soils. These areas would grow samphire (*Halosarcia* spp.) and puccinellia (*Puccinellia ciliata*), and saltbushes (*Atriplex* spp.) on the sandy rises. They would be highly suited to cool-season aquaculture in shallow ponds.
- *Land of moderate potential* would have deeper groundwater, less inundation and lighter (sand over clay) duplex soils. These soils would grow stands of saltbushes and balansa clover (*Trifolium michelianum*), tall wheat grass (*Elytrigia elongata*) and puccinellia *(Puccinellia ciliata)*. Stands of bluebush (*Maireana brevifolia)*, acacia species and highly salt-tolerant eucalyptus species would grow on sandy rises.
- *Land of high potential* would have shallow watertables of low salinity and deep sandy profiles. These sites would be highly suited to the growth of tree species such as *Eucalyptus occidentalis, E. camaldulensis, Melaleuca* spp. and *Casuarina obesa.*

Increasingly, the occurrence of salinity, waterlogging and inundation and their severity can be measured or predicted using combinations of on-ground surveys, air-borne geophysics and hydrological modelling. These techniques could therefore be used to develop a robust predictive capacity for matching saline agricultural enterprises to sites. It is anticipated that overlays of measured and modelled information (salinity, texture, risk of inundation, depth and salinity of groundwater) could be manipulated in geographic information systems to develop prescriptive maps of saltland capability.

Table 1. Products/functions from salt-tolerant plant species in Australia.

Product/function	Species*	Product/function	Species*
Brushwood fencing	22	Organic chemicals	18
Carbon sequestration	1–3, 10–12, 15–17, 20–22	Pulpwood	15, 16
Cineole and/or essential oils	15, 22	Seed	4, 9, 14, 24, 26
Fuelwood	2, 3, 10–12, 15, 16, 20	Tannin	2, 10, 16, 17
Fodder (meat, wool)	1, 2, 4–9, 13, 14, 19, 23–26	Timber products	10, 11, 15
Grain	13	Watertable drawdown	1–17, 19–22
Honey	11, 16		

* Species include:

1. *Acacia ampliceps* (salt wattle)
2. *A. saligna* (WA golden wattle)
3. *A. stenophylla* (eumong)
4. *Atriplex amnicola* (river saltbush)
5. *Atriplex cinerea* (grey saltbush)
6. *Atriplex lentiformis* (quailbrush)
7. *Atriplex nummularia* (old man saltbush)
8. *Atriplex paludosa* (marsh saltbush)
9. *Atriplex undulata* (wavy leaf saltbush)
10. *Casuarina equisetifolia* (coastal sheoak)
11. *C. glauca* (swamp oak)
12. *C. obesa* (swamp sheoak)
13. *Distichlis spicata*
14. *Elytrigia elongata* (tall wheat grass)
15. *E. camaldulensis* (river red gum)
16. *E. occidentalis* (flat topped yate)
17. *E. sargentii* (salt river gum)
18. *Halosarcia* spp. (samphire)
19. *Maireana brevifolia* (small leaf bluebush)
20. *M. halmaturorum* (Kangaroo Island paperbark)
21. *M. thyoides* (scale-leaf honey myrtle)
22. *M. uncinata* (broombush)
23. *Paspalum vaginatum* (salt water couch)
24. *Puccinellia ciliata* (puccinellia)
25. *Spartina alternifolia*
26. *Trifolium michelianum* (balansa clover).

Defining plant capability

Plants on saltland are subject to a range of stresses including salinity, waterlogging and inundation. In general, responses to salinity are well understood (Aronson 1989, Maas 1986). Unfortunately, plants with high levels of salt tolerance do not necessarily have high levels of tolerance to waterlogging or inundation. Furthermore, there have been very few studies of the effects on plants of waterlogging and/or inundation under saline conditions.

Waterlogging causes roots to become energy deficient. This increases their uptake of salt, which adversely affects growth and survival (Qureshi & Barrett-Lennard 1998). Research on Australian tree species shows that some highly salt-tolerant species have exceptional tolerance to waterlogging under saline conditions, while others are sensitive. Figure 2 shows the effects of salinity (increasing to about 76% of sea-water), under drained or waterlogged conditions, on the survival of seven tree species. All trees had similar survival (94–100%) under saline-drained conditions. However only one species (*Casuarina obesa*) had 100% survival under saline-waterlogged conditions.

Figure 2. Effects of waterlogging under conditions of increasing salinity on survival of seven Australian tree species (after Moezel et al. 1988). The plants were grown in drained or waterlogged sand with increasing salinity (7 dS/m per week) for six weeks.

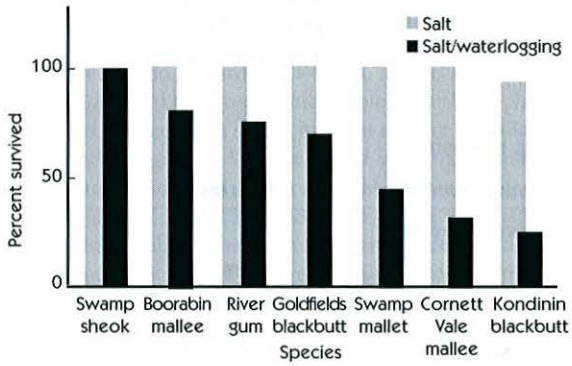
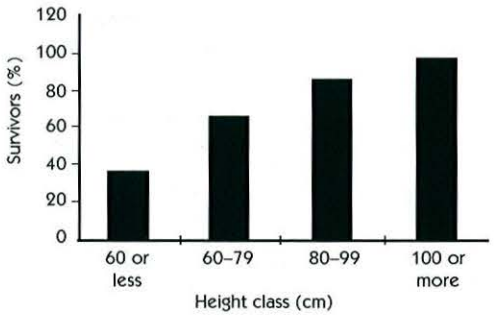


Figure 3. Relation between plant height and survival of river saltbush plants after inundation (after Qureshi & Barrett-Lennard 1998).



Inundation appears to be even more damaging to plants. Despite this (with the exception of rice), there are nearly no documented examples of the effects of inundation on plants. The data in Figure 3 suggest one mechanism by which plants can avoid inundation: grow quickly so that total immersion in the water is avoided. The data are derived from an experiment with clones of river saltbush grown on the banks of the Kabul River in Pakistan. After the plants were established, the river rose and flooded the site for a few days. The tallest plants (100 cm high or more) had greatest survival (97%); the shortest plants (60 cm or less) had lowest survival (36%).

CONCLUDING COMMENTS

Australia faces a substantial and increasing salinity problem. It is essential that income-generating agricultural systems are developed for this land resource. There are two major tasks:

- get the science right;
- change community consciousness.

The second of these tasks may be less obvious than the first. There is a need to engender a change of consciousness about what is possible on saltland. One of the largest problems that we face lies in the scepticism of communities: farming, research and agency. In the face of such scepticism we should remember that the salinisation of land does not mark the end of living systems.

Here is an example of what is meant by a change of consciousness. Many farmers in Australia have thought of salinity as a form of 'land cancer' and what a terrible simile that is. When thinking of cancer, one thinks of debilitating disease with little prospect of cure. However, the analogy is not even remotely appropriate to the facts. An alternative analogy is suggested (Qureshi & Barrett-Lennard 1998). Saltland should be considered to be 'land irrigated with shallow groundwater'. When considered in this (quite accurate) perspective, agricultural options for saltland automatically come to mind.

REFERENCES

Aronson, J.A. 1989, *HALOPH: a data base of salt tolerant plants of the world,* Office of Arid Lands Studies, The University of Arizona, Tucson,

Barson, M. 1994, 'Review of the potential use of saltbush in the Murray–Darling Basin', in *Third National Workshop on Productive Use of Saline Lands*, eds M.A. Schulz & G. Petterson, 15–17 March, pp. 26–31.

Herrmann, T. 1996, 'Puccinellia – maximum productivity from saltland', in *Proceedings of the 4th National Conference on Productive Use and Rehabilitation of Saline Lands*, Albany, pp. 297–302.

Lay, B. 1990, 'Saltland revegetation – a South Australian overview', in *Revegetation of Saline Land*, eds B.A. Myers & D.W. West, Institute for Irrigation and Salinity Research, Tatura, pp. 15–20.

Lloyd, M.J. 1998, 'Saltland pastures – options and constraints', in *Managing Saltland into the 21st Century: Dollars and Sense from Salt*, eds N.E. Marcar & A.K.M. Afzal Hossain, PNM Editorial Publications, Canberra, pp. 92–96.

McCarthy, D.G. 1992, 'Salt tolerant grasses – mediterranean environment', in *National Workshop on Productive Use of Saline Land*, ed. T.N. Herrmann, South Australian Department of Agriculture, pp. 28–35.

Maas, E.V. 1986, 'Salt tolerance of plants', *Applied Agricultural Research*, vol. 1, pp. 12–26.

Malcolm, C.V. 1990, 'Saltland agronomy in Western Australia – an overview', in *Revegetation of Saline Land*, eds B.A. Myers & D.W. West, Institute for Irrigation and Salinity Research, Tatura, pp. 21–25.

Malcolm, C.V. & Clarke, A.J. 1971, *Plant Collection for Pasture Improvement in Saline and Arid Environments*, Technical Bulletin 8, Western Australian Department of Agriculture, South Perth..

Marcar, N. 1990, 'Tree options for utilisation of salt affected land', in *Revegetation of Saline Land*, eds B.A. Myers & D.W. West, Institute for Irrigation and Salinity Research, Tatura, pp. 53–59.

Marcar, N.E., Benyon, R.G., Crawford, D.F. & Nicholson, A.T. 1998, 'Tree growth and water use on a saline site near Wellington, New South Wales', in *Managing Saltland into the 21st Century: Dollars and Sense from Salt*, eds N.E. Marcar & A.K.M. Afzal Hossain, PNM Editorial Publications, Canberra, pp. 128–130.

van der Moezel, P.G., Watson, L.E., Pearce-Pinto, G.V.N. & Bell, D.T. 1988, 'The response of six *Eucalyptus* species and *Casuarina obesa* to the combined effect of salinity and waterlogging', *Australian Journal of Plant Physiology*, vol. 15, pp. 465–474.

Qureshi, R.H. & Barrett-Lennard, E.G. 1998, *Saline Agriculture for Irrigated Land in Pakistan: A Handbook*, Monograph 50, Australian Centre for the International Agricultural Research, Canberra.

Rogers, A.L. & Bailey, E.T. 1963, *Australian Journal of Experimental Agriculture and Animal Husbandry*, vol. 3, pp. 125–130.

Teakle, L.J.H. & Burville, G.H. 1945, *Journal of Agriculture of Western Australia*, vol. 22 (2nd series), pp. 87–93.

Thorburn, P. 1996, 'Can shallow water-tables be controlled by the revegetation of saline lands?' *Australian Journal of Soil and Water Conservation*, vol. 9, pp. 45–50.

Warren, B.E. & Casson, T. 1994, Sheep and saltbush – are they compatible? in *Third National Workshop on Productive Use of Saline Lands*, eds M.A. Schulz & G. Petterson, 15–17 March, pp. 125–129.

TREES FOR SALINE ENVIRONMENTS

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Eucalypts on a mildly saline site.

ABSTRACT

Tree growth on saline land is influenced by species and provenances used, site factors (e.g. seasonal waterlogging) and appropriate management which limit root-zone salt accumulation. While commercial species such as Eucalyptus globulus *and* E. grandis *are slightly salt-tolerant, species such as* E. occidentalis *are highly tolerant. Groundwater use is enhanced when watertables are not too saline (EC < 10 dS/m) and not too deep (< 4–5 m). There are good prospects to enhance tree growth on saline land through exploitation of genetic variation within species such as* E. camaldulensis *by producing improved seed, and also through inter-species hybrids.*

KEY WORDS

Eucalypts, salinity, waterlogging, tree improvement, groundwater, water use

INTRODUCTION

Dryland and irrigation salinity is a serious problem in southern Australia, especially in the 400–650 mm average annual rainfall zones. About 3 million ha are currently affected and dramatic increases are likely in the next 20–50 years. Large-scale tree planting, strategically located in both recharge and discharge areas, can significantly impact on rising watertables and thus reduce the risk of dryland salinisation within integrated land-management systems. Reducing recharge in dryland areas may also help to lessen the rise of watertables in irrigation areas, depending on inherent geological features. However, tree plantings are only likely to impact slowly on the hydrology of salt-affected land. In order to have substantial effects, plantings will need to be adopted rapidly and on a substantial scale (e.g. George et al. 1999). Success will therefore depend on such plantings having commercial value (i.e. suitable for farm forestry).

Trees planted in saline areas may help to stabilise watertables, reduce soil erosion and stream salinity, and provide shelter, shade and direct economic returns from tree products. Trees planted on salt-affected land or above shallow saline groundwater within irrigation districts can also help to lower watertables in their vicinity, by reducing recharge or using groundwater. Salinity benefits can also accrue by irrigating trees with saline drainage waters (e.g. serial biological concentration [SBC] approach [Greenslade et al. 1999]) or pumped groundwater. Opportunities to grow trees commercially and sustainably are greater where groundwater is not too saline (EC < 5 dS/m) and not too deep (within 3–4 m of soil surface), where soils are deep and not constrained by clay and sodic subsoils, and where irrigation water is only slightly saline (EC < 2–4 dS/m), especially on heavy- textured soils.

Choosing more productive and salt-tolerant species and provenances[1] will substantially improve survival and growth rates. The more common commercial eucalypt species and *Pinus radiata* do not grow well in saline and dry environments. Since the majority of dryland salinity is found in the 400–650 rainfall zones, which are usually greater than 150 km from main coastal ports, growing trees for short-rotation pulpwood is generally not financially attractive. Trees are therefore typically grown for firewood, on-farm and sawn timber and non-wood products such as oils. Economic returns from growing trees on saline land should be improved if salt-tolerant and fast-growing genotypes of commercial species can be identified and deployed, and if alternative products, such as biomass (for bio-energy), leaf oil and carbon, become economically attractive.

[1] Provenance is the original geographic source of the seed; due to genetic adaptation to distinctly different environments, seed of different provenances can vary greatly in performance.

In this paper three issues are considered with respect to growing trees in saline areas:

(i) choosing the best species and provenances;

(ii) prospects for genetic improvement; and

(iii) potential to influence local hydrology.

The paper mainly draws on research results from studies with eucalypts.

CHOOSING THE BEST SPECIES

Most currently-recognised commercial eucalypt species, such as *Eucalyptus globulus* (blue gum) and *E. grandis* (flooded gum), are slightly salt-tolerant. In contrast, some species with little current commercial value, such as *Acacia stenophylla* (river cooba), *E. occidentalis* (swamp yate), *E. sargentii* (salt river gum) and *E. spathulata* (swamp mallett), are highly salt tolerant. Several species, including *E. spathulata* and *E. occidentalis*, can survive and grow well when irrigated with saline water (e.g. with drainage water of EC ~10 dS/m where drainage is good [Greenslade et al. 1999]). Interestingly, *E. occidentalis* has recently been shown to have promising pulping qualities (Clark et al. 1999).

Determination of field response to salinity is crucial to predicting likely performance. An example is provided in Figure 1 for *E. camaldulensis* (age 6 years) and *E. occidentalis* (age 5 years) from collaborative research near Wellington, NSW (Benyon et al. 1999). Whilst a 10% reduction in stem diameter was found for

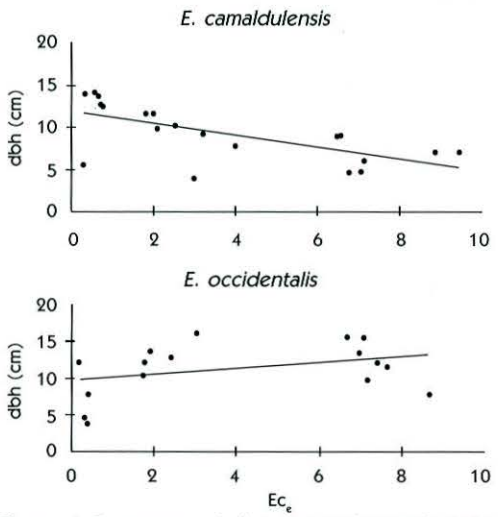

Figure 1. Response of diameter at breast height (dbh) of 6 year old *E. camaldulensis* and 5 year old *E. occidentalis* to increasing root-zone (0–60 cm) mean salinity (EC_e) at a saline trial site near Wellington, NSW (Benyon et al. 1999). The slopes of the linear regression lines differed significantly ($p < 0.01$) between the two species.

E. camaldulensis at an EC_e of about 2 dS/m, this reduction occurred at about 10 dS/m for *E. occidentalis*. Similar responses were found for height and crown volume. It is important to refine these relationships for a range of species and provenances at different sites and, where possible, to determine responses for variates such as biomass and stem volume. It is especially important to devise efficient techniques to determine how these relationships are modified in the field by stresses such as waterlogging.

Trees need to withstand multiple stresses when planted in salt-affected locations, where soils are likely to be subject to seasonal waterlogging and sodic/alkaline soils (due to relatively high sodium levels). Table 1 (see p. 16) provides summary information on likely species' responses to salt, acidity, alkalinity and waterlogging, partly based on reviewed information (e.g. Marcar et al. 1995, Marcar & Khanna 1997, House et al. 1998), results from collaborative species/provenance evaluation trials on saline sites in NSW and other observations.

Growth rates on moderately to highly saline sites are usually slow, with estimated mean annual increment (MAI) for stem volume typically ranging from less than 5 m^3/ha/year to about 10 m^3/ha/year (e.g. Bennett & George 1996). This variation is attributable to differences among species and provenances, sites, plantation age and stocking density.

PROSPECTS FOR GENETIC IMPROVEMENT

In order to improve the capacity of particular species to survive and grow well on saline land, it is necessary to:

(i) evaluate provenances and individual parent tree seedlots (families);

(ii) select promising genotypes; and

(iii) include them in a breeding program to produce improved seed and possibly even clones.

Selection of better performing trees growing on saline sites and their subsequent vegetative production, can produce clones that grow better than unselected trees when planted on saline sites (e.g. for *E. camaldulensis* [Morris 1995]), but results have been variable. The opportunity for genetic improvement through cloning is enhanced when the variation between trees

Table 1. Suitability of selected tree and shrub species climatically suited to farm forestry in southern Australia.

	Salinity	Alkalinity	Acidity	Waterlogging
Acacia dealbata	*	*	*	*
A. mearnsii	*	*	*	*
A. melanoxylon	*	*	*	*
A. saligna	*	**	*	*
A. stenophylla [a]	****	**	*	**
Casuarina cunninghamiana	**	*	**	**
C. glauca [a]	***	*	**	***
C. obesa	****	**	*	**
Chaemaecytisus palmensis	*	*	*	
Corymbia maculata	*	*	*	*
Eucalyptus camaldulensis (northern) [a]	**	**	**	*
E. camaldulensis (southern)	**	**	*	*
E. cladocalyx	*	**	*	*
E. globulus [a]	*	*	*	*
E. grandis [a]	*	*	**	*
E. largiflorens	**	**	*	**
E. leucoxylon	**	*	*	*
E. occidentalis [a]	***	**	*	**
E. polybractea	**	*	*	*
E. robusta	*	*	*	**
E. sideroxylon	*	*	*	*
E. spathulata	****	*	*	**
E. viminalis	*	*	*	*
Grevillea robusta	*	*	*	*
Melaleuca halmaturorum	****	**	*	***
M. uncinata	**	*	*	*
Pinus pinaster	**	*	**	*
P. radiata	**	*	**	*

Salinity refers to electrical conductivity of a saturated soil paste of the average root-zone (approx. 0–60 cm) * = ECe 2–4 dS/m; ** = ECe 4–8 dS/m; *** = ECe 8–16 dS/m; **** = ECe > 16 dS/m

Alkalinity * = pH 7.0–8.0; ** = pH 8.0–9.0; *** = pH > 9.0

Acidity * = pH 6.0–7.0; ** = pH 5.0–6.0; *** = pH < 5.0

Waterlogging * = several days; ** = periodically (several days to weeks); *** = seasonally (several weeks)

Significant variation in growth is likely among provenances of several species, including those marked with '[a]'.

Only limited information is available for responses of some species to these stresses (particularly acidity and waterlogging).

attributable to root-zone salinity can be accounted for. Evidence also suggests that genotypes selected in glasshouse screening trials, where major stresses (salt and waterlogging) likely to be encountered in saline environments are included, should perform better on salt-affected sites than those selected for salt tolerance alone (Bell et al. 1994).

As a first step to evaluating the level of genetic variation in tolerance to salt and waterlogging of commercial species, seedling responses to saline solutions of up to EC 15 dS/m have been tested for several provenances and families of *E. globulus* and *E. grandis* under glasshouse conditions (Marcar et al., unpubl.). Although there was considerable variation in growth between provenances and families, growth reductions due to salt and waterlogging were similar among them (i.e. those that grew best without salt also grew best with salt). Heritabilities for early age growth were high in both saline and non-saline treatments. At higher salinity levels, individual seedlings varied considerably in symptom development. Further research is necessary to determine if the above results hold under conditions of high salinity and in the field.

The level of genetic variation in survival and growth among 113 bulk provenance and individual family seedlots of *E. camaldulensis* is currently being evaluated in duplicate trials at saline sites near Wellington and Deniliquin in NSW using the same design (Marcar et al. unpubl. data). These trials are not irrigated and in both cases trees appear to be using some groundwater. Figure 2 illustrates large differences in height growth among provenances at age 23 months for the Deniliquin site (mean root-zone salinity [EC_e] of 7.3 dS/m); at 3 years, estimated MAI ranged from about 3 to 9 m^3/ha/year among these seedlots. Preliminary co-variate analysis indicates that differences among provenances and families in response to salinity are not significant. The most productive provenances at both sites were from the Lake Albacutya region in north-west Victoria. Differences in survival among provenances were smaller than for growth, although there were large differences among families within provenances.

These trials, and others with different species on non-saline sites, will be thinned to leave the most productive and best form trees to cross pollinate and produce improved seed. In the absence of improved seed, it is recommended that the best provenances should be used for planting similar sites. The best provenances at Deniliquin performed equally well at the less saline site near Wellington, which suggests that the capacity for growth under non-saline conditions may be a useful indicator of growth performance under moderately saline conditions.

Data from 2–3 year old field trials on saline sites in Western Australia and NSW with hybrid clonal lines of *E. camaldulensis* x *E. globulus* (Odie & McComb 1996) indicate substantial variation in height growth and survival, with responses to salinity intermediate between parent species (J. McComb, pers. comm.). Clonal hybrid lines of *E. camaldulensis* x *E. grandis* are currently being planted on a saline site near Deniliquin, NSW (J. Sasse, pers. comm.). Hybrid technology is also being applied by CSIRO Forestry and Forest Products to produce genotypes better adapted to low rainfall conditions. Use of such hybrid clones may provide potential for planting of trees with commercial wood properties that have substantially improved growth and survival in saline and low rainfall environments.

POTENTIAL TO INFLUENCE LOCAL HYDROLOGY

Limited information is available on the ability of different tree species to use groundwater of varying salinity and depth (Thorburn 1996). Although many tree species can continue to use water with an EC of 5–10 dS/m, only the most salt-tolerant trees such as *Melaleuca halmaturorum* (salt paperbark) can use highly saline groundwater (EC > 20 dS/m) (Mensforth & Walker 1996). George et al. (1999) show that tree planting in discharge areas was most likely to lower watertables if salt concentration was < 5000 ppm (EC about 8 dS/m) and aquifers were localised.

Water use by eight year old *E. camaldulensis* trees has been measured using sap flow sensors during summer at a rain-fed site (about 640 mm mean annual rainfall) near Wellington, NSW (Benyon et al. unpubl. data). By artificially restricting horizontal root growth and excluding rainfall with shelters, the contribution of groundwater to total tree water use was determined. Trees that were drawing on groundwater of low salinity (EC ~ 5 dS/m), transpired at a rate of 2 mm/day but trees that were drawing on highly saline groundwater (EC ~ 20 dS/m) used only 1 mm/day. Individual trees were able to use shallow groundwater up to 20 dS/m.

A few studies have shown that water use per unit leaf area or sapwood area is generally comparable between species under similar growing conditions, including saline sites (Morris & Collopy 1999, Benyon et al. 1999, Marcar et al. 1999). The depth and spread of roots is also important. Salinity and waterlogging can lower water-use of plantations by reducing tree growth rates, and hence leaf area, as well as restricting root exploration. The large differences in growth rates between species that are caused by differences in their tolerance to salt, often result in large differences in water use per tree and thus per unit land area.

One potential longer-term problem as trees transpire saline water is that salts accumulate in the soil around their roots (Thorburn 1996). Current evidence indicates that salts can build up during dry periods, within or just below the zone of actively growing tree roots, especially where watertables are shallow and saline. However, if there is sufficient leaching of salts during heavy rainfall events, coupled with improved drainage and lateral subsurface flow of water, the potential for salts to accumulate is minimised, especially in lighter soils and where watertables are deep.

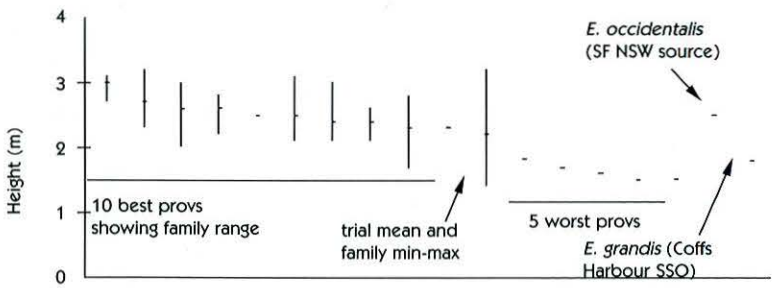

Figure 2. Height growth at 23 months for a number of provenance and provenance groupings of *E. camaldulensis*, each composed of several families in a provenance-family trial planted on a moderately-saline site near Deniliquin, NSW. Within each provenance the range of values for different families is represented by a 'bar'.

CONCLUSIONS

Salt-affected sites present harsh conditions for tree establishment and subsequent growth. Growth potential and salt tolerance varies widely among eucalypt species, provenances and even families-within-provenances. Most commercially grown eucalypt species are best suited to areas of low salinity. However, the best provenances and future improved seed sources, coupled with best management practice, may provide adequate growth rates with more salt-tolerant species at moderate salinities. Use of shallow, saline groundwater may allow trees to maintain adequate growth rates as long as accumulation of salt in the root zone is minimised. A good understanding of site hydrology and options for leaching is crucial.

REFERENCES

Bennett, D.L. & George, R.J. 1996, 'River red gums (*E. camaldulensis*) for farm forestry on saline and waterlogged land in south-western catchments of Western Australia', in *Productive use and rehabilitation of saline lands,* pp. 345–358, Proceedings 4th National Conference and Workshop, Albany, Western Australia.

Bell, D.T., McComb, J.A., van der Moezel, P.G., Bennett, I.J. & Kabay, E.D. 1994, 'Comparisons of selected and cloned plantlets against seedlings for rehabilitation of saline and waterlogged discharge zones in Australian agricultural catchments', *Australian Forestry,* vol. 57, pp. 69–75.

Benyon, R. G., Marcar, N. E., Crawford, D. F. & Nicholson, A.T. 1999, 'Growth and water use of *Eucalyptus camaldulensis* and *E. occidentalis* on a saline discharge site near Wellington, NSW, Australia', *Agricultural Water Management,* vol. 39, pp. 229–244.

Clark, N.B., Read, S.M. & Vinden, P. 1999, 'Effects of drought and salinity on wood and kraft pulps from young plantation eucalypts', *Appita Journal,* vol. 52, pp. 93–97.

George, R.J., Nulsen, R.A., Ferdowsian, R. & Raper, G.P. 1999, 'Interaction between trees and groundwaters in recharge and discharge areas—a survey of Western Australian sites', *Agricultural Water Management,* vol. 39, pp. 91–113.

Greenslade, R., Heupermann, A.F., Marcar, N. & McKinnon, L. 1999, 'Saline groundwater management at Undera, Victoria', in *Managing saltland into the 21st century: dollars and sense from salt,* N.E. Marcar & A.K.M.A. Hossain eds, Proceedings of the 5th National Conference on the Productive Use and Rehabilitation of Saline Land, Tamworth, NSW, 9–13 March 1998, pp. 123–125.

House, S., Nester, M., Taylor, D, King, J. & Hinchley, D. 1998, *Selecting trees for rehabilitation of saline sites in south-east Queensland,* Queensland Department of Primary Industries Technical Paper 52, Brisbane.

Marcar, N.E., Crawford, D.F., Leppert, P.M., Jovanovic, T., Floyd, R. & Farrow, R. 1995, *Trees for Saltland: A guide to selecting native species for Australia,* CSIRO Publications, Melbourne.

Marcar, N.E. & Khanna, P.K.1997, 'Reforestation of salt-affected and acid soils', in *Management of Soil, Nutrients and Water in Tropical Plantation Forests,* E.K. Sadanandan Nambiar & A.G. Brown, eds, pp. 481–525, ACIAR Monograph No. 43, ACIAR, Canberra.

Marcar, N.E., Benyon, R.G., Crawford, D.F. & Nicholson, A.T. 1999, 'Tree growth and water use on a saline site near Wellington, New South Wales', in *Managing Saltand into the 21st Century: Dollars and Sense from Salt,* N.E. Marcar & A.K.M. Afzal Hossain, eds, pp. 128–130, Proceedings of the 5th National Conference on the Productive Use and Rehabilitation of Saline Land, Tamworth, NSW, March 1998.

Mensforth, L.J. & Walker, G.R. 1996, 'Root dynamics of *Melaleuca halmaturorum* in response to fluctuating saline groundwater', *Plant and Soil,* vol. 184, pp. 75–84.

Morris, J.D. 1995, 'Clonal redgums for Victorian planting', *Trees and Natural Resources,* March 1995, pp. 26–28.

Morris, J.D. & Collopy, J.J. 1999, 'Water use and salt accumulation by a plantation of *Eucalyptus camaldulensis* and *Casuarina cunninghamiana* with shallow saline groundwater', *Agricultural Water Management,* vol. 39, pp. 205–228.

Odie, R.L.A. & McComb, J.A. 1996, '*Eucalyptus camaldulensis* x *globulus* hybrids for saline land' in *Productive use and rehabilitation of saline lands,* pp. 345–358, Proceedings Fourth National Conference and Workshop, Albany, Western Australia .

Thorburn, P.J. 1996, 'Can shallow watertables be controlled by revegetation of saline lands?', *Australian Journal of Soil and Water Conservation,* vol. 9, pp. 45–49.

ROBUST SYSTEMS FOR SALINE LAND

challenges in agriculture and conservation

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ABSTRACT

Addressing dryland salinity at discharge sites is increasingly seen as one of the essential tools for 'living with salt'. This paper discusses the importance of a systems approach to saline groundwater discharge. Such an approach takes account of landscape hydrology (and its relationship to climate), salt dynamics, vegetation water use and vegetation growth patterns. Understanding the dynamics of these systems, and knowing how to adapt agricultural and environmental management to maintain dynamic equilibrium, will be an important part of 'living with salt'.

KEY WORDS

Systems, living with salt, groundwater balance, salt balance, discharge

INTRODUCTION

There is an increasing awareness that recharge control may be impractical for many areas at risk of salinisation (Walker et al. 1999, Hatton & George 1999). This has led to a greater focus on the 'living with salt' option that involves managing saline lands for agriculture and other purposes. In adopting this option, it is important that we really understand its implications and how it affects our future. There has been considerable work on the establishment, palatability and productivity of our agricultural systems on saline land (e.g. Jarwal et al. 1996) and more recent work on water use and salt accumulation (Bleby et al. 1997). However, it is still not clear whether these agricultural systems will be stable, even for the medium term. This is made even more difficult since often, even less is known about natural systems in shallow watertable areas (Froend et al. 1987, Jolly & Walker 1996).

Stable systems require consideration of not only the vegetation and groundwater, but also soils, and social and wider environmental aspects. This paper considers only water, salt, plant water use, and vegetation growth requirements and challenges for system stability. If stability of the hydrology and vegetation can be achieved, then superimposition of other attributes can also be considered. It is important to recognise that salinity itself is an unstable situation and that conditions which impinge on discharge areas continuously change. This paper examines the changing environment of the discharge areas due to salinity and how this may impact on the ability to manage them.

SALINITY IS AN UNSTABLE CONDITION

Catchment groundwater balance

Groundwater-related salinity is caused by an increase in recharge (water entering the aquifer) caused most often by the replacement of natural vegetation with cropping and pasture systems. Under natural conditions, catchment discharge (or amount of water leaving the groundwater system) approximates recharge resulting in hydrological balance. Increased recharge, means that catchment discharge must also gradually increase until the system is balanced. This occurs over decades to tens of thousands of years, and is related to the length of the flow path, permeability of the aquifer and the groundwater gradient. The quantity of catchment discharge has little to do with how the discharge areas are managed. It is largely a groundwater response to recharge.

Catchment salt balance

It is commonly assumed that under natural conditions the salt in groundwater systems is in balance (e.g. Jolly et al. 1997), but this is less likely than groundwater volume balance. Salt in most areas comes from rainfall and exits by streams that discharge into the ocean or into saline lakes. As groundwater discharge increases, so does the volume of salt exported from the catchment. This 'salt export to import ratio' can increase by as much as 20 times after clearing. As salt gradually leaches from the catchment, the groundwater freshens

and a salt balance returns. However, the time scale on which this occurs is significantly greater than that required for a 'new' groundwater volume equilibrium.

Form of the discharge

Land salinisation results from the aquifer being unable to transmit all of the recharge to the natural discharge site and saline land occurs along the groundwater flowpath, where one or more factors (e.g. decreases in permeability, thinning or narrowing of the aquifer or a drop in groundwater gradient) combine to bring salt to the surface. Increasing discharge above the discharge capacity of the groundwater system will lead to an increase in salinisation and waterlogging. Depending on the topography, this increased land salinisation may take the form of an increase in the salinised area or an increased discharge per unit area.

Simplistically, the average watertable will rise to the level where sufficient discharge can occur: on steeper land this can be only a small area with high discharge density; in flat terrain it can be a large area with a small discharge density.

There is some evidence that salinity can affect soil properties and this may lead to lower discharge density. A larger salt-affected area would then be needed to achieve the required discharge volume. The effect of engineering schemes such as surface or sub-surface drainage is to decrease the discharge through the land surface by diverting it into streams or disposal basins.

Discharge rate

As groundwater is lost by evapotranspiration, salt is brought into the soil zone. For a discharge rate of 50 mm/yr and a groundwater salinity of 5000 mg/l, this leads to an average increase in salinity in the top 2 m of the soil zone of 500 mg/l/yr (assuming a water content of 25%). For higher discharge rates, shallower soils and more saline groundwater, this can be substantially increased. Over time, this can lead to increased shallow groundwater salinities, higher soil salinities (and even salt lakes) and increased salt washed from the surface. If the groundwater discharge is sufficiently high, seeps can form, leading to gully erosion and focusing of the groundwater discharge in those gullies.

Partitioning the long-term fate of salt into either groundwater or salt lakes and streams, largely determines the long-term viability of those areas for saltland agronomy or conservation of natural systems.

Flooding

Discharge areas naturally occur in low-lying areas and are prone to inundation. As the area of shallow watertables increases, so does the propensity for flooding and inundation. As groundwater becomes more shallow, it takes less water to fill the soil store, and therefore surface runoff occurs earlier. This effect is further exacerbated by the reduction in vegetative cover, which also increases runoff.

DISCHARGE AREAS AS DYNAMIC SYSTEMS

The slowly evolving processes described above are masked by the dynamic processes in discharge areas, which can vary in both space and time. Large variations also occur in the behaviour of different discharge areas.

The behaviour of vegetation in discharge areas and feedback relationships with the hydrology is discussed below. Black box trees (*Eucalyptus largiflorens)* on a semi-arid, saline floodplain of the River Murray transpired little water: 0.1–0.3 mm/d, compared to potential evapotranspiration of 10 mm/d (Thorburn et al. 1993). This was attributed to the infrequent leaching of salt by floods (recurrence intervals 4–15 years) and the low rainfall (~270 mm/yr). If transpiration had been greater, salt would have accumulated more quickly in the soil zone and the vegetation would have been stressed by lack of extractable water. Field investigations showed that the trees extracted the less saline water from the top layer of the soil (Jolly et al. 1993). This dry layer at only 1–3 m above groundwater would then lead to upflow of very saline groundwater. In the absence of flooding, this saline layer would occur throughout the soil zone, so that an extreme dry period could then lead to widespread dieback as occurred in the droughts of the late 1960s and early 1980s.

The River Murray and its anabranches acted as drains for the groundwater system—allowing groundwater levels to equilibrate, and salt to leave the floodplain in groundwater after floods or wash off during floods. The decrease in floods due to development of water storages upstream, together with raised groundwater levels due to locking has changed the balance between salt accumulation during dry periods and leaching during floods. Salt now accumulates for longer periods of time to higher concentrations and is leached less frequently.

In another example, Swamp paperbark (*Melaleuca halmaturorum)* in the Upper South Eeast region of South Australia transpired reasonable quantities of water (1–2 mm/d) all year despite the presence of extremely saline water (70 dS/m) at only 1 m depth (Mensforth & Walker 1996b). This was attributed to

very regular leaching events each year. The shallow watertable leads to moist soils and very rapid recharge by winter rainfall, the watertables rising to near or above the soil surface. After winter, water levels fall, salt accumulates near the soil surface and deeper roots develop to avoid the saline layer (Mensforth & Walker 1996a). In the later summer, trees are extracting from the groundwater, the top of which has been recharged during the winter. Regular leaching means there is less time to accumulate salt and the melaleucas can transpire water more quickly without fully salinising the soil. They have an extreme ability to extract water from saline soils with leaf water potentials down to -7MPa (compared to *E. largiflorens* -4 MPa). In this example, there is little ability for salt to be removed from the plant–soil system except in salt wash off at the beginning of winter. Consequently, groundwater salinities are likely to rise.

Other salt-tolerant species, such as mangroves (Passioura et al. 1992), saltbush *(Atriplex* spp., Slavich et al. 1999), *Puccinellia* spp. and wheatgrass (*Agropyron* spp., Bleby et al. 1997) and even lucerne (*Medicago sativa L.*, Smith et al. 1995) have some of the same characteristics that enable them to adapt to saline conditions:

- low transpiration and hence growth, related to the frequency of major leaching events;
- low leaf water potentials;
- dynamic root systems or the ability for senescence or lower transpiration.

Salt removal from the root zone is required for any plant to function sustainably. The above processes and these plant characteristics limit the ability of vegetation to lower watertables in shallow watertable areas for long periods of time (Thorburn 1996).

DISCHARGE AREAS IN AN EVER-CHANGING ENVIRONMENT

Studies to date give an understanding of the external conditions driving the change in discharge areas and that there is little that management in the discharge areas will do to change these. There is an improvement in understanding of the water-use strategies that salt-tolerant species use to cope and why some are better adapted to certain saline conditions than others, but it is still difficult to understand how *robust* agricultural systems can be designed for saline areas:

1. Consider a salt-tolerant species, such as puccinellia, that senesces in order to avoid saline conditions and emerges when conditions become fresher. Increasingly saline conditions at time of seedling emergence will result in poor yields or persistence of the pasture. Inspection of the upper south-east of South Australia, where drainage is being implemented, showed that the interaction of surface water and groundwater played a large role in the persistence of puccinellia (Walker & Mensforth 1998). This interaction is generally poorly understood but is likely to affect the conditions at emergence. As salinisation increases, it is not clear how sustainable these pastures will be without the regular flooding that has been a natural feature of this region.
2. The transition of soils from being in constantly oxidised conditions to being in alternating reducing–oxidising or constantly reducing conditions caused by shallow watertables can lead to consequences such as changes in soil properties; and release of iron, sulfur and even heavy metals. Export of salt to streams may enable a salt balance to be reached, but may also lead to export of undesirable elements. It may also affect the ability of the roots to penetrate certain sections of the soil profile for either physical or chemical reasons and hence limit their ability to survive the salinity. This is believed to be the case at a study site where the melaleucas died (Mensforth 1996).
3. Extreme climatic events play a large role in shallow watertable areas. Large rain events can lead to expansion of shallow watertable areas and extreme droughts can lead to large areas of dieback and the development of extremely saline conditions. This variability is a key characteristic of Australia's climate, and results in large variations in the conditions with which plants must cope, including soil salinities, available water and waterlogging.

CONCLUSIONS

The above examples are likely to represent only a few of the complexities to be encountered in the development of *robust* systems for saline areas. Such systems must cope with extreme conditions on top of a gradually deteriorating background. The only analogues for managing shallow watertable areas are the irrigated areas of the Murray–Darling Basin. In these areas, sub-surface drainage and groundwater pumping are required to control watertable levels, and have become economically feasible. Disposal basins and export of salt into the river systems are required for a salt balance. Even with engineering schemes, it is unclear for how

long these areas will remain stable. It is generally thought that such engineering options can only be applied sporadically in dryland areas due to the economics of the agriculture, practicalities due to topography and lack of suitable disposal points. Also, the greater complexities in topography and geology mean that long-term management of these areas will be complex. Our ability to adapt to a slowly-changing groundwater systems and highly variable climate will be one of the challenges for the next hundred years. Given that estimates for the area of salt-affected lands may be 30% of the agricultural landscapes, it is imperative that we understand what will happen to this land. *Our inability to deal with this may lead to devastation of some of these landscapes, with increased scalded areas, erosion, weed infestation, irreversible damage to our soils, deterioration of water quality and inevitably a larger area of salt-affected land.*

REFERENCES

Bleby, T.M., Aucote, M., Kennett-Smith, A.K., Walker, G.R. & Schachtman, D.P. 1997, 'Seasonal water use responses of tall wheatgrass (*Agropyron elongatum* (Host) Beauv.) in a saline environment', *Plant, Cell and Environment* vol. 20, pp. 1361–1371.

Froend, R.H., Heddle, E.M., Bell, D.T. and McComb, A.J. 1987, 'Effects of salinity and waterlogging on the vegetation of Lake Toolibin, Western Australia', *Australian Journal of Ecology,* vol. 12, pp. 281–298

Hatton, T.J., & George, R.J. 1999, Evaluation of the WA Salinity Action Plan. (pers. comm.).

Jarwal, S.D., Jolly, I.D. & Kennett-Smith, A.K. 1996, *The salt-tolerant grasses Puccinellia (Puccinellia spp.) and tall wheat grass (Agropyron elongatum): A literature survey of their salt tolerance, establishment, water use and productivity,* CSIRO Division of Water Resources Technical Memorandum 96.7.

Jolly, I.D., Walker, G.R., and Thorburn P.J. 1993, 'Salt accumulation in semi-arid floodplain soils with implications for forest health', *Journal of Hydrology,* vol. 150, pp. 589–614.

Jolly, I.D., & Walker, G.R. 1996, 'Effects of river management on the hydrology and hydroecology of semi-arid/arid floodplains', in *Floodplain Processes,* eds M. Anderson, D.E. Walling & P. Bates, pp. 577–609, Wiley, Chichester.

Jolly, I.D., Walker, G.R., Dowling, T.I., Zhang, L., Morton, R. & Williamson, D.R. 1997, 'Reconstructing historical salt balances and stream salinity trends in catchments of the Murray-Darling Basin, Australia', in *Proceedings of Hydrology and Water Resources Symposium,* pp. 423–28, Auckland, 24–28 November, 1997.

Mensforth, L.J. 1996, 'Water use strategy of *Melaleuca halmaturorum* in a saline swamp', Thesis for Doctor of Philosophy, Botany Department, University of Adelaide, South Australia.

Mensforth, L.J. & Walker, G.R. 1996a, 'Root dynamics of *Melaleuca halmaturorum* in response to fluctuating saline groundwater', *Plant and Soil,* vol. 184, no. 1, pp. 75–84.

Mensforth, L.J. & Walker, G.R. 1996b, 'Water use of *Melaleuca halmaturorum* in a saline swamp', in *Proceedings of the 4th National Conference and Workshop on the Productive Use and Rehabilitation of Saline Lands.* Albany, W.A., pp. 279–254, 25–30 March.

Passioura, J.B., Ball, M.C. & Knight, J.H. 1992, 'Mangroves may salinise the soil and in doing so limit their transpiration rate', *Functional Ecology,* vol. 6, pp. 476–481.

Slavich, P.G., Smith, K.S., Tyerman, S.D. & Walker, G.R. 1999, 'Water use of grazed salt bush plantations with a shallow watertable', *Agricultural Water Management* vol. 39, pp. 169–185.

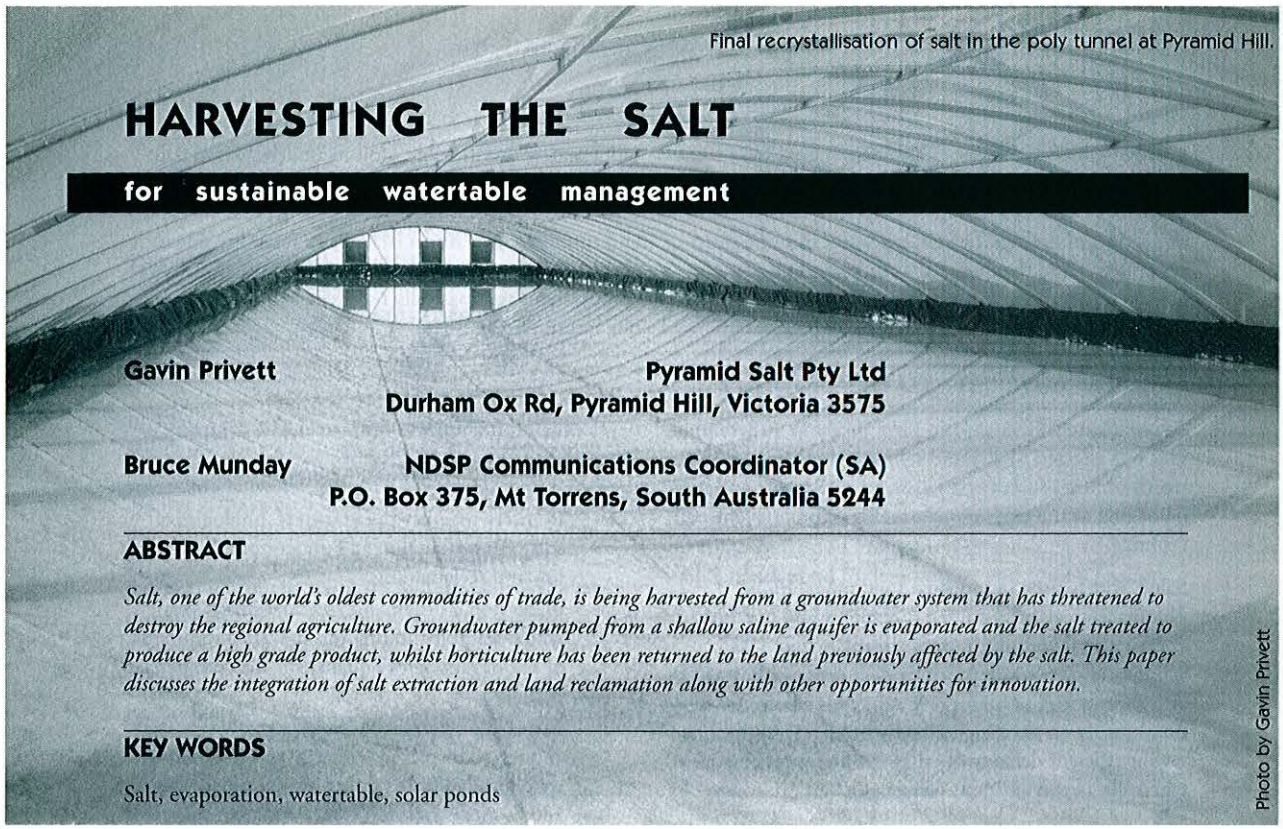
Smith, D.J., Meyer, W.S., Barrs, H.D. & Schwamberger, E.C. 1995, *Effects of soil type and groundwater salinity on lucerne crop daily water uptake and capillary upflow in weighing lysimeters from 1990 to 1993,* CSIRO Division of Water Resources, Technical Memo, CSIRO Division of Water Resources, Canberra.

Thorburn, P.J. 1996, 'Can Shallow Watertables be Controlled by the Revegetation of Saline Lands?' Australian Journal of Soil & Water Conservation, vol. 9, no. 3, pp. 45–50.

Thorburn, P.J., Hatton, T.J. & Walker, G.R. 1993, 'Combining measurements of transpiration and stable isotopes of water to determine groundwater discharge from forests', Journal of Hydrology, vol. 150, pp. 563–587.

Walker, G.R. & Mensforth, L.J. 1998, *Managing dryland salinity in the Upper South East: implications of some recent groundwater studies,* CSIRO Land and Water.

Walker, G., Gilfedder, M. & Williams, J. 1999, *Effectiveness of Current Farming Systems in the Control of Dryland Salinity,* CSIRO Land & Water.



Final recrystallisation of salt in the poly tunnel at Pyramid Hill.

HARVESTING THE SALT

for sustainable watertable management

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ABSTRACT

Salt, one of the world's oldest commodities of trade, is being harvested from a groundwater system that has threatened to destroy the regional agriculture. Groundwater pumped from a shallow saline aquifer is evaporated and the salt treated to produce a high grade product, whilst horticulture has been returned to the land previously affected by the salt. This paper discusses the integration of salt extraction and land reclamation along with other opportunities for innovation.

KEY WORDS

Salt, evaporation, watertable, solar ponds

Photo by Gavin Privett

INTRODUCTION

Prior to European occupation, the billions of tonnes of salt in the Murray–Darling Basin were stored in the geological profile. However, the introduction of land clearing and inefficient irrigation methods by European settler farmers increased recharge to the groundwater systems. Consequently the watertables have risen and mobilised the previously dormant salt. The result has been the salinisation of large volumes of groundwater and an increased discharge of natural and induced saline water to the rivers, lakes and agricultural land.

When saline watertables reach within about 1 m of the ground surface, capillary action causes the salts to be drawn to the surface, thus accumulating through evaporation in the topsoils. Depending on the concentration of these accumulated salts in the topsoil, they can result in degradation ranging from reduced productivity to the inability of the soil to support any vegetation at all.

It has long been recognised that this salinisation process could be reversed by lowering and maintaining the watertable to below 1.5–2 m. As a result, many small and large projects have been undertaken to address the problem of lowering the watertable and so reclaiming the land.

LOWERING WATERTABLES

The first line of attack in lowering watertables is to reduce recharge of the groundwater system. However, the diffuse nature of recharge in many landscapes and the widespread replacement of native vegetation with 'leaky' agricultural systems, often makes it almost impossible to control salinity at its cause (Walker et al. 1999).

Addressing salinity at discharge sites deals only with the symptom of the problem. However, increasingly there is recognition that living with salinity is a price that must be paid. Saltland agronomy using salt-tolerant trees or pastures not only has the potential to control or even lower the watertable, it also utilises the resource for production. However, Thorburn (1996) has shown that revegetating saline lands has a significant effect on watertables only if the depth to groundwater is relatively great (> 3 m) and of low salinity (EC < 10 dS/m) and the soils are fine textured.

Thorburn (1996), and Walker and Mensforth (1998) have also cautioned that salt accumulation in the plant root zone reduces groundwater uptake and may eventually lead to plant death unless the salts are leached away.

Lowering of watertables can also be achieved by pumping or by deep drainage. The problem that arises is the disposal of saline water pumped to the surface or drained from the site. Disposal of water into the river systems is out of the question as these systems are already under threat from high salt loading. Evaporation basins are most effective in disposal of saline waters but in many projects undertaken to date they have been ineffectual as a long-term management tool. The main reasons for the ineffectiveness are capital and running costs, and a lack of sustainability due to accumulation of unsalable salts in the basins or leakage from systems that basically transfer the problem from one location to another.

TURNING ADVERSITY TO OPPORTUNITY

Approximately 50% of John Ross' property at Pyramid Hill was affected by dryland salinity. However, the salt which imposes such a restriction on agriculture and is so damaging to the environment is also a potentially useful resource.

Salt is widely used in industry, food preparation, pharmaceuticals, and animal husbandry and has an annual global consumption of approximately 190 million tonnes. While Australia does export salt, it is also an importer of high-grade salt. This represents an opportunity on sites where the hydrological conditions favour efficient delivery of saline groundwater and where climatic conditions enable efficient extraction of salt.

After identification of saline water-bearing ribbon sands under the property at Pyramid Hill, a research and development program was instigated. The company, Pyramid Salt Pty Ltd, was formed as a vehicle for this research and development with the following objectives:

- to marry together the known technologies of solar salt production and underground pumping for land reclamation;
- to develop a sustainable evaporation system which was self-funding through the production of salt of satisfactory quality for the commercial market;
- to develop manageable systems that were small enough to be placed 'on farm' and that could be strategically located to benefit the environment and farming communities;
- to develop new aquaculture techniques within these evaporation systems.

ONE INDUSTRY'S WASTE IS ANOTHER'S RESOURCE

Preliminary research and development revealed a number of factors supporting commercial salt recovery:

- high salt concentration (approximately 50 dS/m or 35 000 ppm) in groundwater close to the surface;
- suitable groundwater chemical composition to permit fractionation of desired salts;
- reasonably permeable sands with saline water bore yields of at least 1 L/s;
- a climate suitable for extraction by evaporation—the selected site must be in an area where net evaporation is positive. The Pyramid Hill area has a gross evaporation of 1424 mm, rainfall 374 mm and net evaporation of 1050 mm.

Chemical analysis of the water also revealed commercially-valuable salts (e.g. magnesium, potassium and bromide salts) as well as sodium chloride.

The evaporation ponds are all lined with polythene to prevent leakage. This imposes a considerable capital cost, particularly as the polythene is easily perforated by hard lumps of dry clay, however it is an essential step to protect the environment. Salt evaporation pans are also generally very large as the rate of recovery is approximately proportional to the surface area but inversely proportional to the depth of water. The challenge at Pyramid Hill has therefore been to develop an efficient system on the smallest possible area.

Leakage is minimised by locating evaporation ponds adjacent to the bores. Whatever leakage does occur is then recovered again by the 15 pumps which deliver a 1ML/day of saline water to the 20 ha system of ponds.

Gravity takes the water through the series of ponds where initially algae is used to scavenge nutrients from the water. The algae is consumed at a later stage by brine shrimp which can be harvested and marketed as fish food. Other biological processes are used to strip out unwanted compounds and elements such as carbonates, iron and other metals, most of which do not have commercial value.

The hypersaline solution from the last evaporation pond passes to a crytalliser pond where crystals of salt come out of solution, are gathered up with a front-end loader and are taken away to be washed in brine. The salt is then redissolved and finally recrystallised in poly tunnels as high purity sodium chloride.

At this stage aquaculture has not been integrated into the program (other than to market brine shrimp as fish food) since the nutrient levels associated with aquaculture would compromise the main objective of producing high purity salt.

THE COMMERCIAL PRODUCT

It has taken over three years to develop a fully-operational production system and establish viable markets.

In 1999 Pyramid Salt Pty Ltd harvested 2500 tonnes of salt ranging in value from $100 to $300 per tonne. The production target is 5000 tonnes per year. Salt of the highest grade is used in pharmaceuticals and food processing, while lower grade salt finds its way into stock feed and supplements. The viability of the business is brought about by adding value to the salt produced and sourcing new markets for import replacement and export.

The evaporation ponds system has the potential for integration of a salinity gradient solar pond. A salinity gradient solar pond is a shallow body of saline water several metres deep and set up so that there is increasing salinity with depth. Solar radiation entering the pond is stored as heat in the lower layer. This heat (raising the temperature to 80°C) is then available on a 24-hour basis. RMIT University, Geo-Eng Australia Pty Ltd and Pyramid Salt Pty Ltd, with a grant from the Australian Greenhouse Office Renewable Energy Commercialisation Program, is establishing a 3000 cubic metre pond to demonstrate and commercialise the system, generating heat for a range of industrial purposes including power generation.

If the design principles and management practices can be satisfactorily refined it might be possible to power the whole pumping and salt manufacturing process from the captured solar energy.

IMPACT UPON THE WATERTABLE

Pumping has lowered the watertable from approximately 0.5 m below the surface to about 6 m. The soil profile still carries salt which is gradually being leached down into the groundwater and which would present a problem if this water was to be used for irrigation. However, because it is to be harvested for salt, it is an asset.

The reduction in soil salinity has allowed reclamation of much previously-scalded land for agriculture. Clover and grasses have reappeared on what was bare ground and commercial vegetable crops are being grown and sold into Melbourne.

Lowering saline watertables, as a result of land management, is a relatively new phenomenon in Australian landscapes and there is some uncertainty as to the effect this might have on the soil chemistry (Fitzpatrick et al. 1996). Rainfall leaching salts from the upper profile may lead to a high concentration of sodium ions in the exchange complex. The resulting sodic soils would display characteristically undesirable properties such as poor structure and susceptibility to waterlogging and erosion. These problems are most likely on clay soils and can possibly be ameliorated with the application of gypsum.

Given this proviso, there is considerable potential to reclaim saline land while producing a valuable by-product, particularly on relatively small areas that might then be used for high value intensive agriculture.

REFERENCES

Fitzpatrick, R.W., Fritsch, E. & Self, P.G. 1996, 'Interpretation of soil features produced by ancient and modern processes in degraded landscapes: V Development of saline sulfidic features in non-tidal seepage areas', *Geoderma* vol. 69, pp. 1–29.

Thorburn, P. 1996, 'Can shallow watertables be controlled by the revegetation of saline lands?' *Australian Journal of Soil and Water Conservation,* vol.9, pp. 45–50.

Walker, G. Gilfedder, M. & Williams, J. 1999, 'Effectiveness of current farming systems in the control of dryland salinity', CSIRO Publishing.

Walker, G. & Mensforth, L. 1998, 'Managing dryland salinity in the Upper South East: Implications of some recent groundwater studies', CSIRO Publishing.

WHAT ARE SALINE SOILS? WHAT HAPPENS WHEN THEY ARE DRAINED?

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ABSTRACT

Drainage of saline soils is one option for the agricultural or ecological restoration of saline discharge areas. However, the biogeochemical and physical processes that are taking place in saturated, saline soils will vary depending on soil type, nature of groundwaters and period of saturation. Serious environmental consequences, such as a marked decrease in soil permeability, soil structural change, increased erosion, a reduction in water quality and, in the worst instance acid-sulfate conditions may occur within a few days if these soils are drained. However, some saline soil types are more resilient, might change very slowly or not at all, and may be reclaimed for productive use.

KEY WORDS

Saline, sodic, acid sulfate, drainage, water

INTRODUCTION

Salt-affected soils form under different environmental conditions and have diverse morphological, chemical, physical and biological properties. These soils can be grouped based on the types of electrolytes causing the salinity, or on their chemical and physico-chemical properties (Szabolcs 1991):

- salt content, salt composition, and salt distribution in the profile and, in some cases, also in the groundwater;
- exchangeable sodium percentage and sodium adsorption ratio (sodic soils);
- pH conditions and the existence of sodium carbonate (alkaline sodic and saline soils).

Much work has been done on the hydrogeology of dryland saline areas and soil sodicity but there is little published work on the biogeochemical and physical properties or processes occurring in saline soils. One reason for the lack of data is that saline soils, traditionally, have not been considered as 'agricultural production soils'. There is also little published information on the reversibility of these changes as saline soils are drained and may develop into sodic soils.

The objectives of this paper are to briefly discuss:

- development of both natural saline soils and those resulting from changes in land management (including potential saline, acid sulfate soils);
- changes in saline soils caused by drainage and resulting in development of sodic soils (including actual acid sulfate soils).

DEVELOPMENT OF SALINE SOILS

'Naturally saline soils' in Australia are extensive. The 'secondary saline soils', which form following land clearing are more closely associated with processes leading to dryland salinity. In Australia, most saline soils contain chloride as the dominant anion and sodium the dominant cation (Figure 1a). The accumulation of this stored salt is generally believed to originate from the ocean via rainfall and marine deposition in earlier geological periods (Isbell et al. 1983). Following the clearing of upland areas, saline seepages develop rapidly on slopes because of rising saline groundwater tables. When saline soils dry out, halite (sodium chloride) is often the main salt efflorescence formed (Figure 1a). However, there is little information available on the nature of the soils and the salts that they contain.

Changes in salinity and development of sodicity

Sodic soils are believed to have developed from saline soils by fresh water leaching. 'Secondary sodic soils' are known to develop from the drainage of saline soils (Figure 1b). However, the formation of 'naturally sodic soils' is more uncertain because they could have formed directly from the weathering of certain parent materials thousands of years ago and may not necessary have developed from a saline soil (Isbell et al. 1983). A case study conducted in the Mt Lofty Ranges (South Australia) has illustrated that a sodic soil, with an exchangeable sodium percentage >15%, can develop from a saline soil (EC_{se} >8dS/m) when it is drained following the formation of a nearby erosion gully (Figure 1b, Fritsch & Fitzpatrick 1994). These studies have demonstrated the important interrelationships between salinity and sodicity in the context of soil–water–landscape processes and the flocculation and dispersion of clay particles (Fitzpatrick et al. 1994).

Changes in the mobility of colloids and clays

Freshwater throughflow in loamy or sandy surface horizons of drained saline soils in discharge areas leads to the development of sodic layers and to lateral movement of colloids into streams (Figure 1b, Fitzpatrick et al. 1994). Such processes usually predominate in texture contrast soils (duplex soils) in which dense sodic columnar Btn horizons that restrict the downward movement of water occur. This constraint to infiltration leads to waterlogging, tunnel erosion and enhanced lateral movement of water as surface runoff and as shallow groundwater flow in sloping land. Eventually a saline scald is formed (Figure 1c).

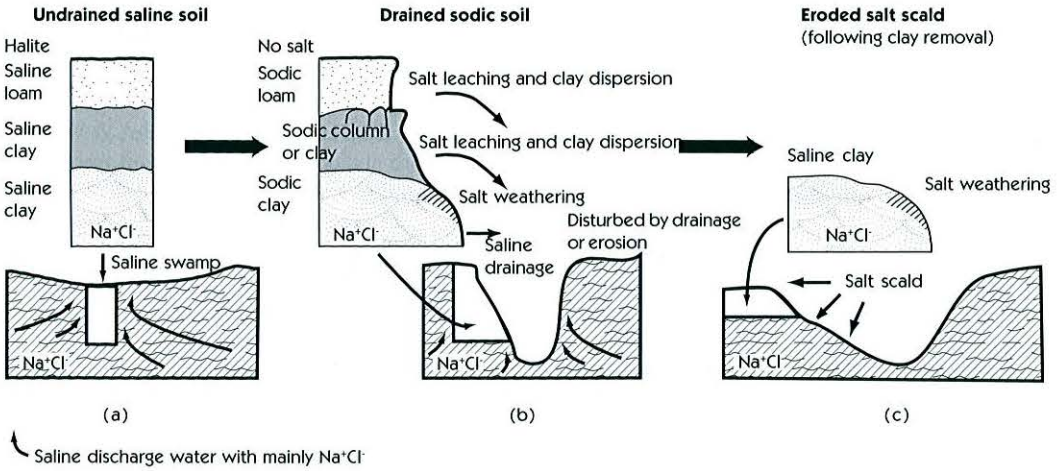
Development of potential acid sulfate soils

In several parts of Australia the codominant anion in saline groundwaters and soils is sulfate (Figure 2a, Fitzpatrick et al. 1992, 1996). Other anions and cations may include iodide, bromide, magnesium, boron and arsenic. These saline soils are associated with geological formations that contain sulfur (i.e. pyrites or sulfate salts) and saline sulfate-rich groundwaters (EC 6–13 dS/m). Flowing preferentially through vertical cracks and old root channels, the sulfate-rich groundwaters seep under pressure to the soil surface where 'potential acid sulfate soils' (pH>6) develop. These saline soils have distinctive, black coloured blotches that are often smelly and soggy because of the presence of sulfidic materials. If the water is evaporated, several types of salt efflorescences and iron oxide gels remain on the soil surface (Figure 2a). This can result in a large build-up of minerals including gypsum ($CaSO_4$), halite (NaCl), thenardite (Na_2SO_4), mirabilite ($Na_2SO_4.10H_20$) and iron oxides (ferrihydrite). These accumulated, soluble salt minerals and iron oxyhydroxide minerals are useful indicators of the soil–water processes operating in these landscapes and provide possible management strategies for reclaiming such salt-encrusted spots, where only salt-tolerant vegetation will grow (usually sedges and rushes).

Changes in potential acid sulfate soils and development of actual acid sulfate soils

If the waterlogged 'potential acid sulfate' soils are disturbed or drained and exposed to the air, sulfuric acid forms and soil pH can drop below 4 (Fitzpatrick et al. 1992, 1996). Also, soil pores become clogged with clay and various types of iron oxyhydroxides form (e.g. schwertmannite, natrojarosite or sideronatrite—

Figure 1. Transformation of a saline soil via a sodic soil to a salt scald.



depending on pH and redox conditions). Consequently, depending on the soil texture, organic matter content and concentration of ions, different types of 'actual' acid sulfate soil layers form (e.g. Figure 2b). Because the soil becomes clogged and less permeable, the sulfate-rich groundwater, which is under pressure, moves side ways or upslope with consequent redevelopment of the cycle of formation of potential acid sulfate soils (Figure 2b). These soils are unstable and erode easily, leaving cemented soil layers, which are relatively resistant to erosion (Figure 2c). The processes give rise to saline scalds, erosion gullies and poor water quality in streams and dams (Figure 2b).

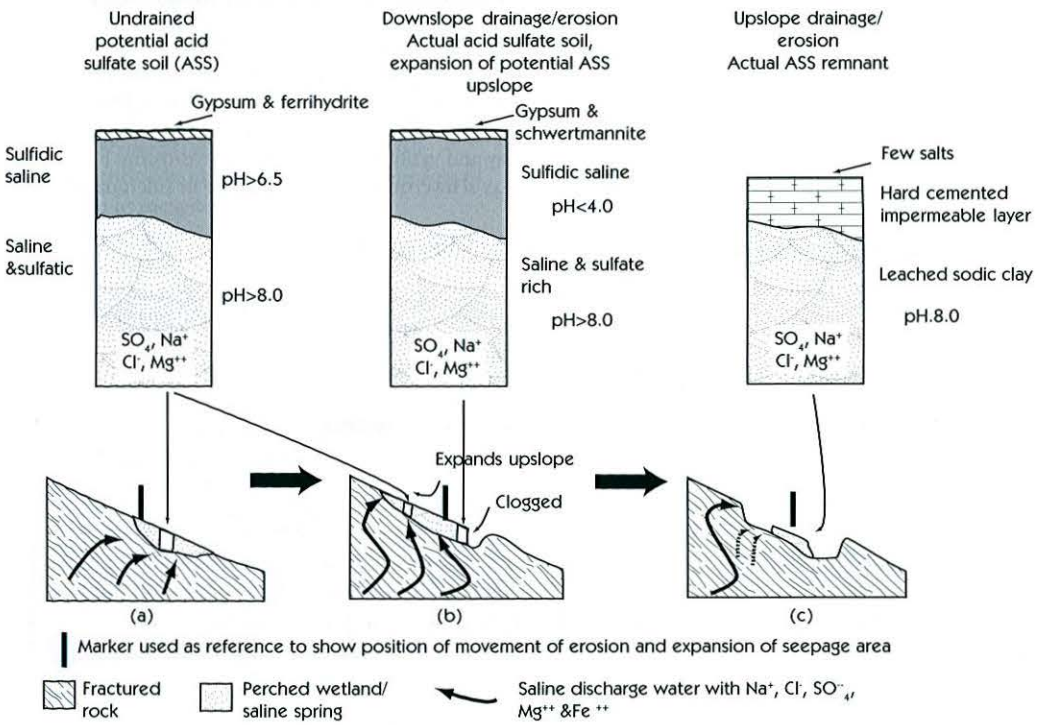
These highly-degraded soils are difficult to rehabilitate because they are acidic, contain high levels of salts, pyrites and iron oxides, are seasonally strongly waterlogged and are of low fertility status (high phosphate-fixing soils). Consequently, new methods for both identifying and treating these soils will have to be developed in order to tackle this problem of national significance. Management requires the control of groundwater, stock exclusion, improvement of drainage, liming and revegetation.

Changes in decomposition and transformation rates of soil minerals

When the saline soils undergo changes, salt efflorescenses on the soil surface are dissolved (Figure 1b). At depth in the sodic soils, where saline groundwater discharges through the subsoil clay layer into the gully, salt crystals develop causing the banks to erode (salt weathering, Figures 1b and 1c). As shown in Figures 2a and 2b, when the potential acid sulfate soils undergo changes, different salt and iron minerals form because of differences in pH and salt concentrations (Fitzpatrick et al. 1996, Fitzpatrick & Self 1997). In the final stage of the acid sulfate soil formation a hard soil layer remains with only few salts (Figure 2c).

The acidification process accelerates the decomposition and formation of minerals in the soils and underlying rocks, and causes an increase in salinity and carbonate formation (Fitzpatrick & Merry 1999). Where these processes have surface expression they develop into unsightly scalds devoid of vegetation and contribute to poor quality catchment water.

Figure 2. Transformation of saline potential acid sulfate soil to degraded actual acid sulfate soil.



Changes in greenhouse gas emissions

Saturated, saline soils are potential sources of greenhouse gases that have not been adequately researched. In a recent study of an area of about 80 km^2 in South Australia, Fitzpatrick et al. (1999) used GIS methodology to estimate that more than 10% of the area was strongly waterlogged and poorly drained, and a further 27% periodically waterlogged. A high proportion also consists of saline discharge areas or potential acid sulfate soils. Depending on seasonal conditions, redox status and the nature of groundwaters (sulfidic, sulfatic or oxygenated), greenhouse gases such as CO_2, N_2O and CH_4 may be emitted. Drainage of these sites may decrease production of these greenhouse gases (Fitzpatrick & Merry 1999).

Changes in soil physical properties

Because clays are flocculated in saline soils and potential acid sulfate soils, and have high organic carbon from saline vegetation, their hydraulic conductivity is expected to be relatively high (>0.1 m/day). The drained sodic soil, which has dispersed clay, low organic matter (from little vegetation) and is hard, has much lower hydraulic conductivity. Changes which occur when an actual acid sulfate soil forms (Figures 2b and 2c) will result in the lowest hydraulic conductivity as these soils also have iron-impregnated layers and thin, impermeable crusts. However, in both cases the relative differences in hydraulic conductivity will depend mainly on the texture and clay minerals present. Finally, because of these large differences in hydraulic conductivity, the relative importance of throughflow in transporting water and colloids to the stream will be reduced and overland flow will be the dominant pathway (Fleming & Cox 1998, Cox et al. 1996). This will increase erosion.

Other soil physical properties including soil water characteristics and bulk density will change as pores are blocked by clay dispersion and clogging.

Changes in runoff water in streams

Changes in physical and chemical properties of soil can cause increased loads of salts, sulfur, iron, heavy metals, arsenic, dissolved organic carbon and colloids in streams, dams and reservoirs (Cox & Ashley 2000). Salinisation of streams and rivers can be a much more significant phenomenon than salinisation of soils (e.g. in areas where the extent of saline seepage is comparatively small, the effect on stream salinity and hence water quality may be quite drastic).

CONCLUSIONS

The processes that follow drainage of saline soils are of national significance and the understanding of these processes needs to be improved. Also, large areas of land with shallow saline watertables are being revegetated but the consequences of changes in soil chemical and physical properties on tree growth and survival are not known (aside from problems associated with the accumulation of sodium chloride in the rootzone). There is a need to predict which types of saline soils will not become productive or will cause further environmental problems if they are drained.

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REFERENCES

Cox, J.W. & Ashley, R. 2000, 'Water quality of gully drainage from texture-contrast soils in the Adelaide Hills in low rainfall years', *Australian Journal of Soil Research,* vol. 38 (in press).

Cox, J.W., Fritsch, E. & Fitzpatrick, R.W. 1996, 'Interpretation of soil features produced by modern and ancient processes in degraded landscapes: VII. Water duration', *Australian Journal of Soil Research,* vol. 34, pp. 803–824.

Fitzpatrick, R.W., Boucher, S.C., Naidu, R. & Fritsch, E. 1994, 'Environmental consequences of soil sodicity', *Australian Journal of Soil Research,* vol. 32, pp.1069–1093.

Fitzpatrick, R.W., Bruce, D.A., Davies, P.J., Spouncer, L.R., Merry, R.H., Fritsch, E. & Maschmedt, D. 1999, *Soil Landscape Quality Assessment at Catchment and Regional Scale,* Mount Lofty Ranges Pilot Project: National Land & Water Resources Audit, CSIRO Land & Water Technical Report.

28/99. http://www.clw.csiro.au/publications/technical99/tr28–99.pdf

Fitzpatrick, R.W., Fritsch, E. & Self, P.G. 1996, 'Interpretation of soil features produced by ancient and modern processes in degraded landscapes: V Development of saline sulfidic features in non-tidal seepage areas', *Geoderma,* vol. 69, pp. 1–29.

Fitzpatrick, R.W. & Merry, R.H. 1999, 'Pedogenic Carbonate Pools and Climate Change in Australia', in *Global Climate Change and Pedogenic Carbonates*, eds R. Lal, J.M. Kimble, H. Eswaran & B.A. Stewart, pp. 105–119, CRC Press Lewis Publishers. Boco Raton. FL.

Fitzpatrick, R.W., Naidu, R. & Self, P.G. 1992, 'Iron deposits and microorganisms occurring in saline sulfidic soils with altered soil water regime in the Mt. Lofty Ranges, South Australia', in *Biomineralization Processes of Iron and Manganese - Modern and Ancient Environments*, eds H.C.W. Skinner & R.W.Fitzatrick, pp. 263–286, *Catena Supplement* No. 21.

Fitzpatrick, R.W. & Self, P.G. 1997, 'Iron oxyhydroxides, sulfides and oxyhydroxysulfates as indicators of acid sulfate surface weathering environment' in (eds.). *Soils and Environment: Soil Processes from Mineral to Landscape Scale*, eds K. Auerswald, H. Stanjek & J.M. Bigham, *Advances in GeoEcology vol.* 30, pp. 227–240.

Fritsch, E. & Fitzpatrick, R.W. 1994, 'Interpretation of soil features produced by ancient and modern processes in degraded landscapes: I A new method for constructing conceptual soil-water-landscape models', *Australian Journal of Soil Research*, vol. 32, pp. 889–907.

Fleming, N.K. & Cox, J.W. 1998, 'Nutrient losses off dairy catchments located on texture contrast soils. Carbon, phosphorus, sulfur and other chemicals', *Australian Journal of Soil Research*, vol. 36, pp. 979–995.

Isbell, R.F., Reeve, R. & Hutton, J.T. 1983, 'Salt and sodicity', in *Soils: An Australian viewpoint*, pp. 107–111, Division of Soils, CSIRO, Melbourne / Academic Press, London.

Szabolcs, I. 1991, 'Soil classification related properties of salt affected soils', in *Characterization, classification, and utilization of cold Aridisols and Vertisols,* Proceedings of sixth international soil correlation meeting (VI ISCOM), USDA, Soil Conservation Service, National Soil Survey Center, Lincoln, NE.

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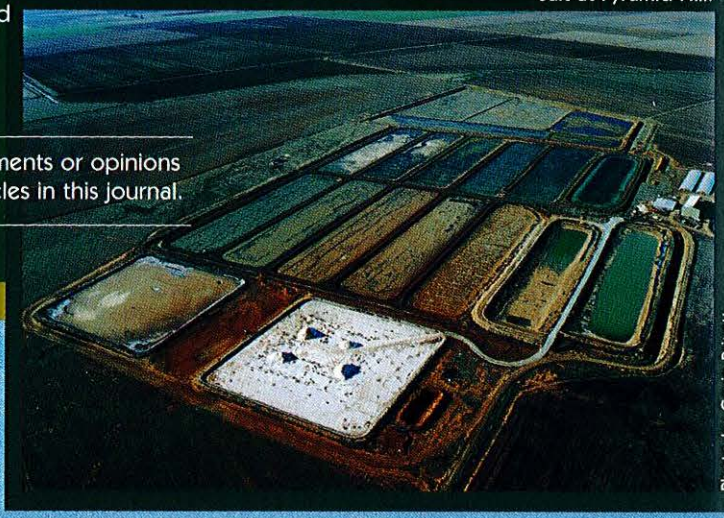
Salt at Pyramid Hill.



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