Managing secondary dryland salinity: Options and challenges

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Abstract

Salt occurs naturally at high levels in the subsoils of most Australian agricultural land. As a result of clearing native vegetation, groundwater tables have risen, mobilising the stored salt and causing adverse impacts to farmland, infrastructure, water resources, and biodiversity. The main action required to prevent groundwater tables from rising is establishment of perennial plants, either herbaceous (pastures or crops) or woody (trees and shrubs). Recent technical and economic research has emphasised how difficult it will be to establish sufficient perennials to get control of groundwater tables. Where watertables are already shallow, the options for farmers are salt-tolerant plants (e.g. saltbush for grazing) or engineering (e.g. deep open drains). The existing options for farm-level salinity management are reviewed, with mixed but somewhat disappointing finding regarding their suitability for addressing salinity. However, there are also a number of good prospects for development of new and better options for plant-based management of salinity, and these are described.

Media summary

Government policies for dryland salinity in Australia have failed because of a lack of economically viable management responses available to farmers. Concerted efforts to develop new options for farmers have recently commenced, and many new plant species are under investigation and development.

Key words

Dryland salinity, environment, policy, water, farming system, policy, R&D

Introduction

Secondary dryland salinity refers to human-induced salinity in non-irrigated areas. The majority of human-induced land salinisation in the world is associated with irrigation; there was an estimated 45 million hectares of salt-affected land in irrigated areas in the 1980s (Ghassemi et al. 1995). Australia is unusual in that the great majority of its salt-affected land is not due to irrigation. Other countries suffering the effects of secondary dryland salinity include the USA (particularly the states of Montana, North Dakota and South Dakota), Canada (the prairie provinces of Manitoba, Saskatchewan and Alberta), Thailand, South Africa, Turkey, India and Argentina.

This paper focuses on the dryland salinity problem in southern Australia but includes brief information on dryland salinity in other countries. It examines the issue at the farm-level but also touches on a range of off-farm issues, including the impacts of dryland salinity on a range of public assets: water resources, infrastructure and biodiversity.

The paper briefly outlines the causes of dryland salinity and provides quantitative estimates of its main impacts in Australia and elsewhere. We describe the array of farm-level responses to salinity currently available in Australia and discuss their viability at the farm level. In relation to these farm-level responses, the paper is primarily relevant to winter rainfall and mixed winter/summer rainfall systems. Although dryland salinity occurs in the tropics, some of the issues are a little different there. We outline current efforts to develop new salinity management options for farmers, and briefly describe some of the prospective new options currently under development. Lessons that other countries might draw from the Australian experience are highlighted.

Causes of dryland salinity

Salt, mainly sodium chloride, occurs naturally at high levels in the subsoils of most Australian agricultural land. Some of the salts in the landscape have been released from weathering rocks (particularly marine sediments) (National Land and Water Resources Audit 2001), but most have been carried inland from the oceans on prevailing winds and deposited in small amounts (20-200 kg/ha/year) with rainfall and dust (Hingston and Gailitis 1976). Over tens of thousands of years, it has accumulated in sub-soils and in Western Australia, for example, it is commonly measured at levels between 100 and 15,000 tonnes per ha (McFarlane and George 1992).

Prior to European settlement, groundwater tables in Australia were in long-term equilibrium. In agricultural regions, settlers cleared most of the native vegetation and replaced it with annual crop and pasture species, which allow a larger proportion of rainfall to remain unused by plants and to enter the groundwater (George *et al.* 1997; Walker *et al.* 1999). As a result, groundwater tables have risen, bringing dissolved accumulated salt to the surface (Anonymous 1996). Patterns and rates of groundwater change vary widely but most bores show a rising trend, except where they have already reached the surface or during periods of low rainfall. Common rates of rise are 10 to 30 cm/year (e.g. Ferdowsian *et al.* 2001).

In other countries, the causes and sources of dryland salinity are similar to Australia in some cases (e.g. north-east Thailand, parts of South Africa) but different in others (Ghassemi et al. 1995). For example, in the USA and Canada, the source of salt was primarily from marine sediments, rather than rainfall, and the cause of water table rise was replacement of grasslands with cropping systems, particularly systems that involve fallow. Fallow-based rotations have largely been displaced from Australian systems, but dryland salinity still occurs in regions where fallow is no longer practiced . In Argentina, current dryland salinity in the north-west of the Province of Buenos Aires is attributed to an extraordinary increase in annual rainfall in an area which is flat and naturally has relatively shallow saline water tables. In north-east Thailand, like Australia, most of the salt-affected land has resulted from forest clearing, but smaller areas are also attributed to construction of reservoirs and to various methods for making salt for commercial sale (which are not causes in Australia). In some coastal areas of Thailand (and various other parts of the world), the source of salt is seawater intrusion.

Impacts of dryland salinity

Reflecting the seriousness of the problem, information on impacts of dryland salinity is vastly more extensive for Australia than for any other country.

The National Land and Water Resources Audit (2001) estimates that the area of land in Australia with “a high potential to develop dryland salinity” is currently 5.7 million ha and will reach 17 million ha by 2050. Western Australia has by far the greatest area at risk, with 80 per cent of current national total, and 50 per cent of the 2050 forecast area. The proportion of agricultural land at risk of being affected to some extent by 2050 exceeds 30 per cent in Western Australia and 15 per cent nationally.

These estimates from the National Land and Water Resources Audit substantially overstate the areas of land that are or will be actually affected by dryland salinity. The criterion used to identify the area at risk was groundwater table depth less than two metres, or between two and five metres and rising, and within the land meeting this criterion only a proportion will suffer reduced productivity from the effects of salinity. For example, for Western Australia, the current area “at risk” is 4.4 million ha, whereas Ferdowsian et al. (1996) estimated that the area where plant growth is affected by salinity was 1.8 million ha. More recent estimates based on remote sensing have suggested that the current salt-affected area in Western Australia is nearer to 1 million ha. Nevertheless, there is no doubt that the impacts are very extensive, and will become more so.

Urban interest in the impact of salinity has been heightened by deterioration in stream and river quality. In the Murray Darling River system, average salinity at Morgan, a key location for benchmarking water quality, will exceed the WHO desirable limit for drinking (500 mg L^{-1}) between 2050 and 2100 (Murray Darling Basin Ministerial Council 1999). Salinity is rising in most rivers of southern Australia (Hatton and Salama 1999).

According to George *et al.* (1999b), in Western Australia, without massive intervention, most or all of the wetland, dampland and woodland communities in the lower halves of catchments will be lost to salinity. There are at least 450 plant species and an unknown number of invertebrates which occur only in these environments and are at high risk of extinction (State Salinity Council 2000; Keighery, 2000).

Increased flood risks have been studied for only a small number of case studies (e.g. Bowman and Ruprecht 2000). Extrapolating from these, George *et al.* (1999b) concluded that, with the predicted two- to four-fold increase in area of wheatbelt land with shallow watertables, there will be at least a two-fold increase in flood flows.

Infrastructure at risk has also been identified. According to the National Land and Water Resources Audit (2001), assets at high risk from shallow saline watertables by 2050 include 67,000 km of road, 5,100 km of rail and 220 towns.

Impacts of dryland salinity in other countries include the following:

- In the Northeast Plateau of Thailand, around 10 per cent of the area has been estimated as salt-affected (Arunin, 1992). An earlier estimate of Limpinuntana and Arunin (1986) based on satellite imagery was that there were 2.85 million ha of salt-affected soils in the area (approximately 17 per cent of the total area) and that 10.8 million ha has the potential to become saline.
- In the great plains of the USA, estimated areas of dryland salinity in the 1980s were 121,000 ha in Montana and around 60,000 ha each in North Dakota and South Dakota (USDA 1989).
- In South Africa, the Berg River in the western part of the Cape Province has suffered increasing salinity due to dryland salinity in wheat growing areas of its catchment (Flügel 1991).
- In the eastern part of Argentina, some millions of hectares of land are affected by flooding and dryland salinity to some extent (Ghassemi et al 1995).

History of policy responses

In the 1980s, many people started to take dryland salinity seriously, particularly in the states where the problem was most obvious: Western Australia, South Australia and Victoria. The basic ‘prescription’ was to increase water use of agricultural systems by:

- Increasing water use of annual crops and pastures
- Establishing high water using perennial crops and pastures
- Establishing trees
- Preventing further clearing in susceptible regions

The main aim was to prevent watertable rise, and there was an implicit assumption or hope that action taken by landholders would be sufficient. There was some investigation of engineering responses (particularly drainage). Salt-tolerant plants were planted in some scalded areas, although outside a small group of enthusiasts, this was mainly for cosmetic reasons.

The National Landcare Program (NLP) emerged in the late 1980s in response to salinity and other land degradation problems. The philosophy was for local participation and priority setting, landholder co-operation and joint action. By 1997 there were over 3,200 locally based Landcare groups (Anonymous 1997). However, volunteer participation seemed to reach its limits (Curtis and Van Nouhuys 1999). Further, evidence began to emerge that the sorts of small scale interventions being undertaken under the banner of Landcare were not being effective in preventing or even slowing the emergence of salinity.

In 1997, the Natural Heritage Trust (NHT) was established. Its design was partly in response to concerns that Landcare was not achieving sufficient change on the ground. The NHT differed from Landcare in having a greater emphasis on partial subsidies for on-ground works. In turn, the National Action Plan for Salinity and Water Quality (NAP), has attempted to respond to concerns that NHT funds were not sufficiently well targeted, and with a recognition that some regions have more urgent (or sometimes more politically important) salinity problems than others. The NLP, NHT and NAP are programs of the national Government. Over broadly the same time period, individual states also developed their own salinity policy plans (e.g. Anonymous 1996, Anonymous 2000). Altogether, these policies and programs represent a very substantial emphasis by governments on natural resource management in agriculture, with salinity as a particularly focus. Despite this emphasis, the current scientific knowledge of salinity indicates that we have made relatively little progress towards changing practices on the scale that would be effective in preventing groundwater rise, and thereby dryland salinity.

Current state of knowledge

In the past decade, and especially the last five years, there has been a dramatic improvement in knowledge of salinity and its management. Some of this new knowledge is forcing us to reconsider what it will really take to successfully manage salinity. Key aspects of our current understanding are summarised here.

- It is much harder to prevent rising water tables and saline discharge than was previously thought. The area of land under perennial vegetation needs to be very great (in excess of 50 per cent in most cases) if salinity is to be controlled at the catchment scale (George *et al.* 1999b) rather than just locally (George *et al.* 1999a).
- Increasing the water use of existing annual crops and pastures alone is not sufficient.
- The range of assets under threat is much broader than agricultural land, and includes water resources, town infrastructure, roads and biodiversity. Water quality issues are of major concern in eastern Australia, particularly because the city of Adelaide is partly reliant on the River Murray for its water supply. The deterioration of water quality in rivers is also adversely affecting irrigators, who draw on that water, and biodiversity in the rivers.
- Some assets can only be protected by engineering methods. Examples include a number of rural towns in Western Australia for which revegetation of surrounding farms will not help (Dames and Moore – NRM, 2001).
- There is significant variability in the responsiveness of groundwater flow systems to management interventions. Regional-scale systems (e.g. in part of the Murray-Darling Basin) are least responsive. There is greater scope for management of salinity in localised systems (more common in Western Australia) although the challenge remains very great even there.
- With large areas already affected by salinity and further increases unavoidable even with major interventions, options for making productive use of saline land are clearly very important.

There has been a rapid growth in interest among farmers in engineering responses to salinity, although there remain some areas of controversy and uncertainty about that.

There also remains considerable interest in the use of perennials for recharge management, although efforts are now focused much more than they were previously on developing new perennial options that are profitable in their own right, in order to achieve adoption at sufficient scale to have an impact on salinity.

Possible farm management responses

A number of high-water-using farming systems are in use around Australia. Those that have been relatively widely adopted have been attractive to farmers primarily based on their production and profit advantages compared to alternative systems. Their contribution to management of the water table may have been considered, but in most cases as a secondary factor.

More productive annuals

Substantial efforts to improve the performance of annual crops and pastures through plant breeding and agronomy has had a large impact on “water use efficiency” but minimal impact on water use. For water use to increase, the annual plants would need to transpire longer in spring thereby creating a large dry soil “buffer”. For this to occur, crops and pastures would generally need to be tapping a substantially increased soil volume and the scope for such changes in limited, especially for cereals. There is evidence of increased water use in annual pastures such as *Ornithopus* spp. (serradellas) where selection for indeterminance and rooting depth in hostile sub-soils has been successful (Nutt 1999). While deeper-rooted annual pasture plants can more fully dry the profile in spring than the more shallow rooted annuals they replace, they have limited capacity to respond effectively to summer rainfall and are likely to be less effective in water use than a well-adapted perennial. A future requirement will be for productive annuals that perform effectively in mixtures with perennials, particularly in low rainfall regions where the productivity and persistence of perennials can be poor if grown as a monoculture.

Perennials for recharge areas

Using perennial plants to reduce recharge in agricultural regions remains a challenge. Current commercial use of perennials is dominated by a small number of plants (e.g. Lucerne, *Medicago sativa;* Phalaris, *Phalaris aquatica*; Tasmanian blue gum, *E. globulus*) and the spatial extent and diversity of suitable perennial species is lower in regions with low rainfall, particularly if they have drier summers. There are currently no perennial options among traditional grain cropping species, so continued grain cropping in salinity threatened areas depends on the success of perennial pastures, shrubs and trees, or on engineering responses (below).

Current successful examples of perennials vary widely in form and function. This raises the prospect that an expanded array of perennials can be developed to allow much wider adoption in the future.

Perennial form ranges in a continuum from tree through shrub to herb and there is a strong link between form and product outcome. Herbaceous species (e.g. lucerne, perennial grasses) are closely linked to livestock production while trees have generally produced structural timber. Currently, shrubs are generally used for fodder production (tagasaste) but wider and/or multiple uses are possible (i.e. acacia for fodder, wood chips, seed and chemical extracts). Similarly, a much wider array of uses is now envisaged for woody perennials, as discussed later.

System configurations can be helpfully categorized as segregated (permanent perennial pasture, forestry plantation), rotated (phase farming using lucerne) or integrated. Systems can be integration in space (alley systems and inter-row elements) or in time (companion cropping using cereals and lucerne).

A number of currently useful perennial plants are described below with attention given to their climatic adaptation and the systems into which they fit. We also draw attention to gaps in the array of current perennial plants.

- *Herbaceous perennial pastures* are a prominent landuse, producing forage for a range of livestock production systems. Sown perennial grasses are an established component of many high rainfall permanent pastures. They are mainly based on exotic species (Phalaris; Perennial ryegrass, *Lolium* spp.; Tall Fescue, *Festuca arundinacea;* Cocksfoot, *Dactylis glomerata*) originating from temperate climatic zones. More recently, species of sub-tropical origin such as Kikuyu (*Pennisetum clandestinum*) and Rhodes grass (*Chloris gayana*) are also beginning to have an impact and are of particular relevance to recharge control because of their summer activity. Native grasses are widely distributed in eastern Australia but enhancing remnant populations rather than new sowings is the major interventiuon despite the availability of a number of commercial cultivars. Key challenges for perennial grasses revolve around extending their use into more stressful environments (e.g. low rainfall zones, acid soils and waterlogged soils). In moving into lower rainfall environments, an associated challenge is the development of systems to allow the integration of perennial pastures with cropping. Lucerne is the most widely used herbaceous perennial legume and is well suited to rotational systems (phase farming). However, its use is currently constrained by plant and soil factors such as intolerance to acidity, waterlogging and low rainfall as well as management factors such as the requirement for intensive grazing management. So far, perennial legumes other than lucerne have been confined to high rainfall zones, where species such as Birdsfoot trefoil (*Lotus corniculatus*) are rated as having wider potential.
- *Shrubs* are a rarer component of current land-use systems for recharge areas because they rarely outperform herbaceous perennials in profitability when grown for forage, and because industries that might utilize woody forms have yet to be fully developed. The most prominent and successful shrub is tagasaste, which is estimated to have been sown on 100,000 ha, mainly in Western Australia. Adoption of tagasaste has occurred because it is able to recover water and nutrients on certain deep and infertile soils with poor water holding capacity. For this reasons it is more productive than shallower rooted alternatives. Additional factors have been the development of low cost direct seeding systems and systems of utilization with cattle that avoids the need for high cost pruning to make the feed available to livestock while maintaining a balance between woody plant structures and higher quality growth of leaves. Tagasaste, like other shrubs, can be established in a plantation but it is also suited to alley systems with pastures or crops grown in the inter-row. The isolated success of tagasaste highlights the need to identify more plants with this growth form for use in settings where herbaceous perennials are unsuited or in integrated systems with other crop or pasture species. A major advantage of shrubs is that they offer the opportunity to accumulate growth and exploit it at times of critical shortage when other sources of feed for livestock are in short supply.
- *Trees* have been planted on agricultural land in substitution for long-term pastures in high rainfall zones. The uptake of commercial tree plantations was assisted during the 1990s by low profitability

> of livestock-based enterprises that dominated in areas with more than 700 mm annual rainfall. Much of the commercial activity has been based on Tasmanian blue gum (*E. globulus*) but other species for both timber and wood chip for paper production have been used. The productivity of Tasmanian blue gum plantations declines with declining rainfall and they become unprofitable compared to other land uses in lower rainfall areas. The cut off point depends on relative commodity prices, but has in recent times been considered to be about 600 mm. In marginal rainfall zones, tree performance can be enhanced by planting in water accumulating positions in the landscape and in agro-forestry plantings (alley planting). Plantation tree production for timber is not a major land-use in areas receiving less than 600 mm, with Maritine Pine (*P. pinaster*) being one of the few examples of commercial initiatives. The use of agro–forestry in lower rainfall areas has been highlighted as a land-use opportunity and development of mallee (*Eucalyptus* spp.) has proceeded in Western Australia with eucalyptus oil, activated carbon and energy as expected co-products. The production system based on alley plantings of mallee species suited to regular harvest and coppice regeneration is a major departure from traditional timber production and highlights an important opportunity for low rainfall agro-forestry across southern Australia.

Efforts to develop new species of perennial plants for commercial production are now underway. One attractive proposition is pursuing the development of perennial wheat. While the advantages of success in this project are obvious, the remaining hurdles are great.

One important hurdle is the wide variety of climatic and soil conditions and farming systems for which perennial options are needed (Ewing and Dolling 2003). Identification and selection of new species of perennial pastures offers the greatest prospect for success in providing a suitably diverse array of profitable perennial options in the short to medium term (and perhaps the long term). The range of possible new species is very great and includes species from a wide array of genera. Examples showing early promise include species from the genera *Lotus, Dorycnium, Medicago, Melilotus* and *Trifolium* (legumes), *Chloris, Digitaria, Panicum, Setaria* and *Bothriochloa* (grasses) and *Cichorium, Plantago* and *Ptilotus* (forbes).

More challenging will be the development of new woody perennials (trees and shrubs). Nevertheless a systematic search for possibilities among native Australian plants is underway. Table 1 shows early results from this search, demonstrating the wide variety of possibilities and some of the possible products.

Ratings given here are provisional, and are relate ONLY to the potential suitability of the species for making each product. They do not include any weighting for growth performance or economic outcome, so are not "recommendations" for growers. They are however "recommendations" for further investigation by researchers.

Plants for discharge areas

A common response by landholders to salinity has been to fence off affected areas and then to manage any plant growth with low intensity grazing. Where such areas are sufficiently large, some producers have looked to improve productivity by introducing plants that are tolerant of the stresses experienced low in the landscape: salinity, waterlogging and inundation. Plant choice is dependent on the expected level of salinity and waterlogging stress in addition to usual soil constraints such as fertility and acidity. While a group of plants has been identified that can tolerate salinity and waterlogging, production rarely matches that possible in unstressed environments.

Legumes as a group are at the low end of the salinity and waterlogging tolerance range. Among the most tolerant species so far identified, balansa clover (*T. michelianum)* and Persian clover (*T. resupinatum)* have been widely sown in areas with mild salinity and their tolerance of waterlogging has made them profitable over large areas. Burr medic (*M. polmorpha*) and woolly clover (*T. tomentosum*) have rarely been sown in discharge zones but have become naturalised in some areas. A perennial legume, strawberry clover (*T. fragiferum*) also has an established commercial role in saline areas but this perennial only persists where water is available for almost all of the year. A major gap is an array of legume species capable of tolerating substantially higher levels of salinity and with general adaptation to a full range of saline soil environments. While it is expected that genera such as *Melilotus* will provide new opportunities there is no indication that legumes will be found for situations where salinity is severe.

Table 1. Preliminary ratings of potential woody perennials in terms of suitability for use in manufacture of three products, medium density fibreboard, particleboard, and fine paper from chemical pulp (1 = best quality source, 2 = next best). Source: Graeme Olsen, pers. comm. (2003).

Species	Distribution	MDF*	PB	Paper
Acacia lasiocalyx	wheatbelt	1	2	2
Acacia saligna	wheatbelt	1	1	
Agonis flexuosa	wetter fringes			2
Alyogyne huegelii	wheatbelt	2	2	1
Anthocercis littorea	wheatbelt	1	1	2
Bursaria occidentalis	wheatbelt	2	2	
Callitris glaucophylla	wheatbelt	1	2	
Casuarina obesa	wheatbelt	2	2	
Codonocarpus cotinifolius	wheatbelt	1	1	
Dryandra sessilis	wheatbelt	2	2	
Eucalyptus loxophleba ssp. liss.	wheatbelt	2	2	
Eucalyptus rudis	wheatbelt	1	2	
Grevillea leucopteris	wheatbelt	1	1	
Grevillea candelabroides	wheatbelt			1
Grevillea leucopteris	wheatbelt	1	1	1
Gyrostemon ramulosus	wheatbelt	1	1	
Hakea oleifolia	wheatbelt	1	1	
Jacksonia sternbergiana	wheatbelt	1	2	
Melaleuca preissiana	wetter fringes	2	2	
Senna pleurocarpa	wheatbelt	2	1	2
Taxandria juniperina	wetter fringes	1	1	1
Trymalium floribundum	wetter fringes			2
Viminaria juncea	wetter fringes	1	1	2

*MDF = Medium density fibreboard, PB = Particleboard, Paper = Fine paper from chemical pulp

Salinity tolerance is more highly expressed in some grasses and two species have been widely used commercially. Puccinellia (*Puccinellia ciliata)* is more salt-tolerant and waterlogging-tolerant than is tall wheat grass (*Thinopyrum elongatum*) but both species have been usefully introduced into saltland pastures. A key issue is the maintenance of pasture production and quality in the absence of a companion legume.

Shrubs are the most salt-tolerant and waterlogging-tolerant options currently available, but their adoption has been constrained by the relatively high costs involved in their establishment and by concerns about the quality of their forage for livestock. Initially landholders with severe salinity looked on species like saltbush (*Atriplex* spp.) and blue bush (*Maireana brevifolia*) as tools for rehabilitating severely salinised areas and plantation style systems were used. Experience has indicated that livestock production from saline areas is enhanced when sheep have access to both saltbush and other higher quality forage. This has given rise to saltbush being more widely used on less severely degraded saltland sites, where the plants are sown as rows or alleys with inter-row plantings of species providing higher quality feed. In this way the investment costs of pasture establishment are kept lower, a mixture of pasture species is available and a synergy is established between the perennial shrub (which keeps the water table suppressed) and inter row species (which benefit from reduced salinity through leaching). Producers have noted that saltland pastures that provide high quality grazing opportunities in autumn have an economic impact greater than predicted by biological productivity because they reduce the need for expensive and labour-intensive supplementary feeding of livestock. This explains the profitability of such systems despite relatively high initial investment costs.

Availability of salt tolerant crops such as wheat would greatly impact the management of salinity and conventional, interspecific and transgenic breeding approaches are being used to genereate increased salinity tolerance. Although the development of cereals with substantial salt tolerance is likely to be some time off, eventual success seems likely. If ultimately successful, one can envisage a system based on cropping between alleys of the above salt-tolerant and waterlogging-tolerant shrubs, which could lower water tables locally and allow some improvement in growing conditions for crops.

More likely to succeed in the short term are efforts to select more productive lines of currently grown salt-tolerant shrubs suitable for grazing. Despite the large areas of land suitable for such shrubs, very little effort has gone into selection or breeding of improved lines.

Engineering

Engineering methods may provide an alternative or a supplement to management with vegetation. On farms, shallow surface drainage contributes to prevention of water table rise and reductions in water logging and has been widely adopted for many years.

Many farmers would like to repair salinised land and continue with traditional agriculture, if that is possible. To this end, taking a lead from farmers in the Upper South-East of South Australia, many farmers in Western Australia have been installing deep open drains to enhance discharge. Early research on deep open drains in WA found that they reduce groundwater levels within only a few metres of the drain on high-clay soils and rarely more than 40 metres on favourable soils (Speed and Simons, 1992; Ferdowsian *et al.* 1997). However, more recent research on drains at Narembeen in WA has found positive impacts over considerably greater distances. It now seems clear that their effectiveness ranges from very high in some locations to extremely low in others. A challenge is to identify accurately and cost-effectively those locations where these drains can be effective.

Probably an even greater challenge is the cost-effective and environmentally safe disposal of discharged waters from deep open drains. There remains a tension in WA between the farming community and regulatory authorities, and its resolution is greatly hampered by lack of knowledge of the risks and impacts from different disposal options.

A full range of engineering responses to salinity are currently the subject of detailed investigation in WA, in the state government's Engineering Evaluation Initiative. In addition to drainage options, this is examining siphons, relief wells and pumps as alternatives.

Proposals to construct major regional engineering systems, fed by pumping or drainage from agricultural land, have been made (e.g. Belford 2001; Thomas and Williamson 2001). Particularly in view of the very great resources involved, these proposals would need very careful investigation before funding could responsibly be provided.

It is worth noting that drainage options are likely to be less politically acceptable for dryland salinity mitigation in eastern Australia, particularly in those locations where the main salinity concerns relate to rivers rather than land salinisation. The higher population density in eastern states may also contribute to greater community resistance due to concerns about aesthetic impacts of widespread installation of prominent drainage systems.

Feasibility of the options

For strategies that aim to keep groundwater tables at bay (i.e. perennials on recharge areas), the requirement for success is a very high level of adoption. There is still debate and discussion about what proportion of the landscape would need to be sown to perennials, but all the proportions under discussion are dramatically higher than are currently present on farms. This leads to the conclusion that perennials need to be commercially attractive to farmers. Without this, there seems no prospect of them being adopted on the scale needed to effectively manage salinity (Pannell 2001).

Kingwell *et al.* (2003) collated existing evidence on the economic performance of current salinity management practices on cropping-oriented farms, and completed a large number of additional analyses for grain growing regions of southern Australia. They concluded that lucerne is currently profitably on at least some areas of most grain farms. The indicated areas of production are small relative to the scale that would be necessary to control salinity over whole catchments, but they would contribute to local water-table management. Soil acidity and water logging are key factors inhibiting expansion of the area suitable for lucerne.

Trees and shrubs are not yet profitable over large areas in grain-growing regions. Oil Mallees appear to have prospects if grown within reasonable transport distance of processing plants.
There are some issues that are not specific to particular perennials.

- Farming systems based on perennials often require more intensive management than do annual plants. Not all farmers have the capacity (financial and/or management) to meet these requirements (Cary *et al.* 2002).
- In higher rainfall zones not too distant from cities and major towns, uptake will be limited by demand for land for uses other than traditional large-scale agriculture (Barr *et al.* 2000). This demand results in small farms, high land prices relative to its value for agricultural production, and a group of land managers who are not driven to embrace innovative commercial farming practices to anything like the same extent as are traditional farmers.

The challenges for strategies that allow farmers to cope with high water tables (salt-tolerant plants, deep-open drains) are somewhat different. They do not require adoption at huge scale, but can be evaluated at whatever scale they are applied to. The economic viability of salt-tolerant plants also has an additional advantage over perennials intended to prevent watertable rise: salt-tolerant plants are established on land that has a low productive value for other uses. Their viability therefore depends on whether their productivity is sufficient to offset establishment costs, and on how long they persist. Long-term persistence has been demonstrated in a large number of cases in Western Australia, but may be more problematic in areas with significant lateral movement of groundwater, due to accumulation of salts in the root zone. Kingwell *et al.* (2003) concluded that saltbush-based systems are often profitable, though usually not highly profitable. O'Connell and Young (2002) conducted a detailed analysis of the economics of saltbush systems. They concluded that the economics most favour saltbush on moderately saline areas. On highly saline areas, the productivity of saltbush is low. On slightly saline areas, the productivity of saltbush is higher, but so is that of competitive land uses, like barley. In general, commercially viable saltland pasture systems are low input in character.

An economic analysis of deep open drains on agricultural land by Ferdowsian *et al.* (1997) reached negative conclusions about their cost effectiveness, but given the new evidence that is emerging about their effectiveness in at least some situations, further research and analysis is needed. It is striking that there is so much current investment by WA farmers in deep open drains despite the lack of economic analysis to support their viability. From a community-wide perspective, the knowledge gap is even greater, as fully evaluating the economics of drains is complicated by the prominence of downstream concerns, particularly where those concerns relate to environmental impacts of intangible value.

The implications of all this seem to be that:

- there is scope for enhanced salinity management with existing options, and
- there is a need for considerably more work to prove and improve the options.

For plant-based options, there is a key need for R&D to develop more profitable new options (both herbaceous and woody, and for both recharge and discharge areas). This is being undertaken by the CRC for Plant-Based Management of Dryland Salinity, which involves nine core partners from four states (http://www.crcsalinity.com).

For engineering options, there is a need for more information about their performance in different circumstances, their design, their economics and their downstream impacts.

Lessons from the Australian experience

In some ways, the situation in Australia is unique, so some of the specific lessons from the experience with salinity are primarily of local relevance. However, there are a number of broader lessons that would apply generally to any large environmental impact resulting from agriculture.

One cannot expect dramatic action from farmers to address environmental problems unless they have available effective management options that are cost-effective. If the environmental impacts occur primarily off farm, and a large response is required of land managers, the management options need to be profitable in their own right. If the benefits occur on farm but will be in the distant future, or the required response is large relative to the impacts avoided, again the management options need to profitable (or nearly so).

Government policies designed and implemented in the absence of suitable options for farmers to adopt have failed badly, despite the expenditure of very large sums of public money. Policies for such issues need to pay attention to the availability of economically viable management responses, and support the development of new responses if needed.

Conclusion

Salinity is such a multifaceted issue that one needs care when drawing generalisations about it. All of the farm management responses outlined here have their place in at least some situations in some locations, and none is appropriate in all cases. Nevertheless, some important generalisations are possible, including the following.

Firstly, our knowledge of salinity has advanced rapidly in Australia, and we are better placed to chart a well-considered path forward than we have ever been. Unfortunately the new knowledge reveals that comprehensive prevention of dryland salinity is substantially more difficult that previously assumed.

Secondly, each of the sets of existing farm-level options for salinity management has problems or limitations of various kinds. Existing perennial plants suitable for recharge areas are usually not profitable on a sufficient scale to fully control watertables. Existing plants suitable for saline and waterlogged soils in discharge areas are profitable to some extent, but not so strongly as we would wish. And the dominant engineering response being explored by farmers, deep open drains, is variable in its effectiveness and hampered by uncertainties about where it will work and what the downstream impacts will be.

Fortunately there are good prospects among the plants currently being investigated. It will, no doubt, take some time before these prospects are delivered as commercial products. However, at least we can say for the first time that a serious effort is underway to develop the technologies that farmers have, in fact, needed all along. The difficulty of meeting this challenge is summarised well by Ewing and Dolling (2003).

> Evolutionary changes to farming systems based on a shift in input costs and product prices as well as technical innovation has been the norm for Australian agriculture. The advent of salinity as a major field problem has added a natural resource management driver to the forces for change. The transition from an agricultural system based on annuals to one with perennial plants at its core is revolutionary rather than evolutionary in concept. The extent of likely change is such that the transition will occur over several decades requiring protracted revolutionary fervour from all those involved as new plants and system come to fruition. (Ewing and Dolling, 2003, p.13)

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