What are the management strategies for preventing dryland salinity? Summary of the current state of the sciences

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Introduction: the dryland salinity problem

Dryland salinity is one of Australia's most serious environmental and resource management issues; and scientists, land managers, and governments are still coming to terms with the magnitude of the salinity problem and the strategies needed to manage it. The National Land and Water Resources Audit (NLWRA, 2001) concluded that about 5.7 million ha are at risk or affected by dryland salinity and that this could increase to over 17 million ha in the next 50 years. In the Murray-Darling Basin, more than 7 million ha of grazing and cropping country are under threat. Increasing salinity of our river systems inevitably follows dryland salinisation as groundwater flows into the streams and salt washes from the surface of saline soil. Salinity trends in our rivers are of major concern, with a number of rivers in Western Australia already too salty for human consumption. The Murray-Darling River system is salinising at an accelerating rate (Williamson *et al.*, 1997), and it is predicted that Adelaide's drinking water will fail to meet international standards 40% of the time by 2020 (NLWRA, 2001). Even though millions of hectares of land are threatened by salinity, the major cost to the community will come from declining water quality (NLWRA, 2002). The river systems of the Murray-Darling Basin support irrigated agriculture and horticulture, tourism, and important natural ecosystems, as well as supplying most of the domestic and industrial water for South Australia. The prognosis for dryland salinity in Australia is not good, but our understanding of the problem is improving, and increasing investment will support innovation and broaden the available management options.

Approaches to combat dryland salinity

There are three sets of options for addressing dryland salinity. The first is to reduce groundwater recharge by reintroducing deep-rooted perennial plants or by using engineering options to intercept fresh water (e.g., surface interception drains). The second option is to enhance groundwater discharge and to intercept salty groundwater before it enters the rivers and store it as safely as possible elsewhere (e.g., pumping saline groundwater into disposal basins). The third option, although not a solution for dryland salinity, is to learn to live with more salt in the landscape and to adopt salt-tolerant agriculture and innovations, such as saline aquaculture. The above options are often likely to be used in combination, depending on the location and the specific dryland salinity issues to be addressed. Given the difficulty of reversing stream salinisation, it is very important to prevent the interception of salt stores with groundwater in areas where we still have the opportunity to do so. It is important to emphasise that, unless the cause of the salinisation is addressed, the land and water resources will continue to salinise. This paper will focus primarily on management options that address the cause of salinisation and that can be taken up by individual landholders. As such, it will cover recharge reduction with brief consideration of engineering options but will not address salt-tolerant agriculture.

Recharge reduction strategies will only be effective solutions to dryland salinity if they result in lowered groundwater levels. For water tables to be lowered, the volume of water entering the groundwater system (the recharge) must be reduced such that it is less than the volume of water that flows out of the groundwater system (the discharge). Many of our groundwater systems have a small discharge capacity because there is little gradient to move the water and the underground aquifers are composed of low-permeability clay and sand. Where discharge capacities of groundwater systems have been calculated, they usually fall somewhere between 10% and 50% of the current recharge rates associated with agricultural systems. Recharge rates are variable, depending on such factors as rainfall and soil properties; but water moving below the root zone of annual crops and pastures (deep drainage) usually ranges between 15 and 130 mm per year (Stirzaker *et al.*, 2000), while groundwater discharge capacities are often in the order 0.5 to 10 mm per year (e.g., Nulsen *et al.*, 1986; Allison *et al.*, 1990; George, 1992). The consequence is that, to stop groundwater levels rising, large reductions in recharge are required. This infers a need to establish deep-rooted perennials over large proportions of agricultural catchments. The consensus of the hydrological community is that change in land use over small areas or changes to farming systems based on annual crops and pastures will not be sufficient to avoid worsening salinity in southern Australia.

Further to the large scale of land-use change required to lower water tables is the likely time lag before a salinity response occurs. While rates of recharge might be reduced quite soon after the re-establishment of sufficient perennial vegetation, it might take several decades for significant changes in groundwater levels to occur. Lag times will be greatest in large regional groundwater systems. In such situations, saline discharge to rivers may continue to increase long after recharge has been reduced (Hatton and Salama, 1999;

NLWRA, 2001). In contrast, small local groundwater systems might exhibit responses within a decade of land-use change. The groundwater systems of the Murray-Darling Basin have recently been classified into local, intermediate, or regional groundwater flow systems to help identify the likely responsiveness of different parts of the basin to recharge reduction strategies (Coram *et al.*, 2000). Given the lag times implicated for less-responsive groundwater systems, it is highly likely that engineering options, such as groundwater pumping, will be needed in combination with land-use change in some locations.

Land-use options for recharge reduction in southern Australia

Annual pastures and crops fall a long way short of the recharge reduction targets that need to be met if we are to avoid worsening dryland salinity. It is true that better managed pastures and crops do use more water; but if we are to be effective in combating salinity, we need to make annual crops mimic a perennial system (e.g., through opportunity cropping); and there have to be new production systems based on deep-rooted perennial species. A summary of the options currently available follows, drawing on Stirzaker *et al.* (2000).

Perennial pastures

Within the < 800-mm annual rainfall zone, perennial grasses are already part of the established farming systems. Perennial pastures generally have greater water consumption than annual pastures. For example, on field trials near Wagga Wagga, New South Wales, perennial pasture treatments (phalaris, cocksfoot, sub clover) resulted in a one-third to one-half reduction in deep drainage compared to annual pasture (ryegrass, silver grass, and sub clover) from 1994 to 1997 (White *et al.*, 2000). There were also substantial benefits in animal production from establishing and liming perennial pastures. Although an improvement over annual species, perennial grasses are not able to reduce recharge to the levels required to match the discharge capacity of the groundwater systems, especially where rainfall exceeds 600 mm per year and is winter dominant (Stirzaker *et al.*, 2000). This is because perennial grasses have shallow roots compared with native woodland species and hence are less effective in controlling recharge from episodic events, such as very wet winters. Particularly large discharges of salt into the river system are recorded from the 600- to 850-mm rainfall zone (MDBMC, 1999), making this zone a priority for salinity mitigation.

Lucerne (*Medicago sativa*) is probably the closest to being able to compete economically with annual systems, and it has the capability for substantially larger water consumption compared to annual species. For example, Ridley *et al.* (2001) observed greater rooting depth and water use in lucerne and less deep drainage compared with annual pastures and crops. In the 600-mm annual rainfall zone of northeastern Victoria, they calculated that drainage water losses were likely to occur under annual species in 55% of years, while drainage losses were limited to 6% of years under lucerne. Other workers have demonstrated large increases in annual evapotranspiration from lucerne compared to wheat and annual pasture (e.g., Nulsen and Baxter, 1986; Carbon *et al.*, 1982) and smaller rates of recharge (e.g., Kennett-Smith *et al.,* 1990).

There are still some limitations to widespread adoption of deep-rooted perennial pastures. For example, with lucerne, the favourable soils that are needed (well drained; pH > 4.8 $CaCl_2$) are not always present in our dryland farming regions. There are perceived risks in establishment of lucerne. Careful rotational grazing is needed; and management changes to maximise returns, such as greater stock numbers and later lambing, can be a disincentive (Cocks, 2003). Native perennial pastures have some potential, particularly where limiting site conditions, such as low pH, low soil fertility, and low water-holding capacity, reduce the prospects for establishing and maintaining current commercial grass and legume cultivars. Mitchell *et al.* (2001) report an initial evaluation of perennial native grasses and the identification of 20 accessions (12 species), including *Austrodanthonia*, *Microlaena*, and *Themeda*, for field evaluation in the 500- to 600-mm rainfall zone in southeastern Australia. In addition, there are a range of other perennial legumes that might have some value (Cocks, 2001).

The introduction of perennial pasture is a positive step for salinity management, but it more often represents incremental improvement in water use rather than the capability to meet groundwater recharge reduction targets. It is emphasised that heavy grazing severely reduces the water use of perennial pastures. Good green leaf area must be maintained if the potential water use and recharge reduction is to be realised.

Phase farming and companion cropping

Research has shown that lucerne phases within a crop rotation appear profitable (Bathgate and Pannell, 2002) and can be effective in reducing drainage of water below the root zone (e.g., Ward *et al.*, 2003). Here lucerne is used to dry the soil below the normal rooting depth of annual crops and pastures to provide a buffer against drainage. The buffer refills during the subsequent cropping phase before being re-established in a subsequent lucerne phase. The reduction in drainage can be substantial, in the order of 70% for the situation where a pasture with roots to 3 m depth is incorporated into a rotation (3 years of pasture followed by 3 years of wheat) in an area with 575-mm annual rainfall (Stirzaker *et al.*, 2000). Maximising the reduction in drainage and maximising crop production means managing the crop and pasture phases to keep in step with dry and wet seasons.

Companion farming is where annual cereals are oversown into a perennial pasture system. The pastures can be native grasslands or deep-rooted legumes, such as lucerne. Farmer experience from north central Victoria indicates better economic returns from companion cropping than from grazing. However, yields from companion-cropped wheat were often less than from wheat in the absence of lucerne (Harris *et al.*, 2003). There is likely to be a trade-off in production through competition for water and problems obtaining a clean harvest. Companion farming is potentially more effective in drainage reduction compared to phase farming, given the year-to-year rainfall variation and the cost associated with changing phase.

Opportunity cropping

Overall water use in annual cropping systems can be increased by establishing crops in both winter and summer where rainfall and soil conditions allow. This opportunistic cropping is suited to northern New South Wales and Queensland, where summer rainfall is significant and the clay soils have high water-holding capacity. Research on the Liverpool Plains area of northern New South Wales showed that annual cropping increases drainage of water below the root zone to six times greater than that under the native vegetation of the area (native perennial grasses and eucalypt woodland) whereas opportunity cropping reduced drainage to twice that under the native vegetation while also increasing grain production (Ringrose-Voase and Cresswell, 2000).

Farm forestry

Forestry for sawlogs and pulpwood is largely undertaken in the > 800-mm annual rainfall zone. Tree growth, wood volume, and commercial viability all decline with rainfall. In the 600- to 800-mm rainfall zone, high-value and low-volume products are needed. Some of the candidates are specialty timbers, essential oils, native foods, and tannin (AGO, 2001). However, these tend to be small specialty markets readily satisfied with a small area of trees. The way forward looks to be multiple-purpose harvesting where a number of products are taken from native trees. An example from Western Australia is Mallee eucalypts that are being harvested for oil to produce industrial solvents and pelletised charcoal for filtration, and the waste biomass is used for electricity generation (Bartle, 2001). On their own, the products are not profitable; but together the system may approach returns from cropping in some instances. The production of ethanol and methanol to replace fossil fuels is another possibility. A sawlog might still be a primary product from a low-rainfall forestry system; but other products, such as charcoal and biomass energy, could, in combination, increase the profitability of farm forestry (AGO, 2001).

As an alternative to conventional block plantations, trees can be grown in carefully selected landscape positions where they can harvest more water than annual rainfall. An example is the break-of-slope tree plantation where trees are located to intercept water moving horizontally across the landscape. At break-of-slope positions, there may be susceptibility to waterlogging in crops or pasture; and these can be ideal locations for tree planting. The objective is to use a disproportionately high quantity of water from a given area of trees. The water availability confers production benefits to the tree crop, meaning they can be grown profitably in drier regions than are usually considered for commercial forestry. In southern Australia, trees have the potential to use around 1,000 to 1,400 mm of water per year where that much is available (e.g., Benyan, 2000).

Agroforestry

Agroforestry is a combination (mixture) of trees and pasture, such as alleys of trees separated by pasture, as distinct from plantation forestry. Spaced trees or tree belts within pasture paddocks can harvest water from an area far beyond their canopies and use the water left behind by pastures. Thus, for a given area of trees, a disproportionately high reduction in deep drainage can be obtained. Mixing trees and crops invokes competition for light, nutrients, and water. Depression in crop yield occurs adjacent to tree belts, often to 30 to 40 m away, although shelter benefits can sometimes confer a zone of yield enhancement (e.g., Nuberg *et al.*, 2002). Pasture yield can be depressed close to trees (e.g., Bird *et al.*, 2002), but this is not always the case. It has been observed that edge rows in tree belts exhibit enhanced growth but also require greater silvicultural management to maintain tree form and, hence, product quality. Agroforestry will be directly profitable only if the value from tree products or from shelter exceeds the amount of displaced pasture and any decline in pasture production due to this competition (Lefroy and Scott, 1994). However, trees can confer other benefits in addition to reduction in recharge, such as protecting against soil erosion and contributing to more favourable pasture species mixes (through shading). The best prospects for successful agroforestry remain, however, in the higher-rainfall areas where the tree component has a direct economic value (Stirzaker *et al.*, 2000).

The attractiveness and cost-effectiveness of recharge reduction

For perennial plants to be widely adopted, they need to be economically competitive with annuals. Most currently available land-use options that are effective in reducing recharge appear less profitable at an enterprise level compared to current agricultural options (Pannell, 2001), with the main exception being lucerne in those environments for which it is suited (e.g., Bathgate and Pannell, 2002). Perennial pastures do have the advantage of supporting the production of existing commodities that have well-established markets. Widespread adoption is still a challenge but seems more tractable than the widespread adoption of woody perennials.

Low-rainfall forestry is potentially the most effective land-use option for reducing recharge to the levels required for management of dryland salinity. However, to be successful, it must be widely adopted; and with the exception of the few niche industries in particular regions, such as oil mallee (Bartle, 2001; Herbert, 2000) and Tasmanian blue gums (*Eucalyptus globulus*) (Burdass *et al.*, 1998, cited in Pannell, 2001), low-rainfall farm forestry does not exist in a commercially viable form. The major obstacle is finding markets of sufficient size and value to drive land-use change at the necessary scale (Stirzaker *et al.*, 2000).

The analysis of profitability in this context doesn't include benefits from ecosystem services, such as enhancement of biodiversity, stock shelter, reduced erosion, carbon sequestration, economic diversification, aesthetics, and amenity value. There are many benefits from increasing native perennial vegetation in our landscapes, but we have difficulty in ascribing a dollar value to these, and hence they are usually omitted from economic analysis. What is certain is that environmental sustainability is increasingly important to consumers, and international markets are beginning to reflect this. Ecosystem services are likely to be increasingly recognised and valued; and as markets develop, they will be increasingly traded, thus providing an important driver for land-use change.

A new land-use mosaic: exploiting variation in soil and topography

The above discussion on land-use options and their adoption has been largely on an enterprise level, although our cropping and pasture farming systems obviously contain a complex array of different pasture and crop types in different locations on the farm, different crop rotations, and different grazing practices. There is an under-explored opportunity for reducing recharge, perhaps even with positive consequences to the economics of the farming operation. That opportunity is greater recognition of the variation in soil and topography across the farm and the opportunities encapsulated in better matching land use to capability. There is a small but increasing body of information showing variation in agricultural productivity across individual paddocks and farms. Analysis of cropping paddocks is showing that much of the profit comes from only part of the areas being cropped while some parts of the farm even lose money. The poorly producing areas can be season specific and, for example, be waterlogged in wet years but outperform other zones in dry years. However, some of the poor areas might not be sufficiently profitable to warrant continuation in crop or pasture with the associated expenditure on lime and fertiliser. These areas potentially offer an opportunity for revegetation with suitable perennial species to reduce recharge and farm input costs.

Our farms of the future will have increased commodity production from their best land with inputs, such as lime and fertiliser, concentrated on these higher-producing zones. This maximises the return on investment. The remainder of the farm will be managed for ecosystem function and the provision of services, such as hydrological balance, the maintenance of habitat, and shelter. That is not to say there can't be direct commercial return from this part of the farm; opportunities could include wood products, oils, native foods, and tourism (e.g., farm stays). Leading farmers are already recognising the whole-farm benefits that come from such an approach. Targeted planting of woody perennials does not necessarily mean a net cost from having smaller areas of crop or pasture. There are examples of demonstrated value from shelter (lambing percentages), local water table drawdown, increased pasture production and quality in some zones, increased property value, diversification of income, and opportunities for environmental certification, to name a few.

Engineering options to manage salinity in southern Australia

Groundwater recharge can be reduced by intercepting fresh water through the use of contour banks and shallow interceptor drains. The aim is to accelerate removal of runoff and shallow subsurface water flow by diverting water from hill slopes into dams or into the river system and thus avoiding infiltration, waterlogging, and groundwater recharge on lower-lying areas. This technique has primarily been applied in the wheatbelt of Western Australia (e.g., McFarlane and Cox, 1990). It is most relevant to higher-rainfall areas and works best on duplex soils.

The second set of engineering options has the objective of increasing the discharge capacity of the groundwater system or intercepting saline water to reduce the impacts on such assets as water resources, infrastructure, or important ecosystems. As such, these are treating the symptoms caused by excessive recharge rather than treating the cause. Groundwater pumping and deep drains are the most common interventions. Where fresh-water aquifers interact with saline groundwater, it is sometimes feasible to pump the fresh water to the surface, thereby reducing the upward pressure on the saline water bodies and reducing saline discharge into the waterways. The fresh water can be returned to the river system or used in high-value enterprises, such as intensive horticulture. Groundwater pumping is dependent on the permeability of the regolith[1] material at the screened depth. Care has to be taken that the decreased pressure in the fresh-water aquifers doesn't result in their contamination with saline groundwater.

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[1] The layer of disintegrating and decomposed rock fragments, including soil, immediately above the solid rock forming the earth's crust.

Engineering options that deal with the pumping or drainage of saline water are more problematic, as the salt has to be disposed of safely. Saline groundwater is commonly pumped to evaporation basins where the water evaporates, leaving the salt behind. The pumping of saline groundwater is expensive and generally has only local effects on groundwater level. The high costs of groundwater pumping contrast sharply with the returns from conventional dryland agriculture. However, it is a viable strategy to protect high-value assets and is the only option in cases where catchment revegetation would be too little or too late to save the asset (Campbell *et al.*, 2000). The Murray-Darling Basin Commission has used groundwater pumping extensively to intercept saline groundwater before it discharges into the Murray River system, and the strategy has been effective in 'buying time' for the river system. The limitations of groundwater pumping are the high cost, the lack of aquifers with sufficient permeability, and the difficulty in disposing of the saline groundwater.

Subsurface drainage can be established below the water table to collect groundwater inflow and prevent water tables from reaching the root zone of agricultural crops. These are expensive to install and maintain but are being seen as an option by farmers with salinised land in Western Australia. As with groundwater pumping intervention, the removal of saline water through deep drains also has the problem of safe disposal of the effluent. Releasing saline (and sometimes highly acidic) groundwater into the surface drainage network is seldom legally or socially acceptable. The only exception might be discharging into streams that are already saline, as is the practice in Western Australia, in order to protect valuable assets. Passing salt to another part of the landscape or to a downstream community is not an effective way to control salinity.

A comprehensive review of engineering options for dryland salinity management, including numerous case studies, has recently been compiled by the National Dryland Salinity Program (NDSP, 2001).

Conclusions

Dryland salinity poses a considerable challenge, especially given the advanced state of salinisation in some areas, the often small and long-delayed catchment response to management intervention, and the lack of cost-effective management options. It is important that we take a realistic view, supported by scientific facts, of the scope and nature of the dryland salinity problem. The salinity problem is such that the future is not likely to be business as usual for dryland agriculture.

No single land-use option or industry or engineering approach is the answer to dryland salinity management in Australia. Combinations of options will be needed as appropriate to the local circumstances. Further, our future farming practises will not be designed solely around salinity but will address agricultural production within the context of larger-scale ecosystem and landscape processes. Land management will have multiple objectives including restoration of ecosystem function (e.g., hydrology, nutrient cycling, maintenance of habitat) to ensure sustainability of agricultural production.

Land-use options that partially reduce recharge, such as establishing greater areas of perennial pasture and introducing perennials into cropping rotations, will generally not prevent dryland salinity but will only delay the onset. However, these are likely to be realistic options to help buy time while more complete solutions are developed.

When we have new farming options that are directly profitable and effective in recharge reduction, then it might be reasonable to expect changed land use over large areas to mitigate dryland salinity without the need for additional large public investment. In the meantime, targeted land-use change needs to be encouraged, through subsidies and other policy mechanisms, in those locations where there are high off-site benefits. This infers highly localised treatment for the protection of high-value assets (e.g., rivers, roads, buildings, and wetlands), responsive local groundwater systems, and knowledge of the location of the salt stores being mobilised. Such circumstances will only apply to a minority of agricultural land. Revegetation incentives that are spread broadly and not well targeted are unlikely to be effective.

Positive progress in finding management options to minimise the impacts of dryland salinity will come through farmer innovation, supported by research and development with the objectives of:

(a) Developing products and associated markets and industries that enhance the economic viability of farm forestry in the 600- to 800-mm annual rainfall zone.

(b) Developing new pasture and cropping systems, based on perennial species, that are economically competitive with the current annual-based agriculture.

(c) Understanding and measuring the commercial benefits that come from improved ecosystem function (ecosystem services) and developing markets for these.

(d) Identifying workable mosaics of land use that increase commodity production from some areas of the farm while generating ecosystem services from the remainder.

(e) Providing quantitative analysis of land resources and catchment processes to enable appropriate targeting of investment in land-use change.

(f) Developing integrated land management options that confer multiple environmental benefits, for example, combining high-value agriculture with woody vegetation (for recharge control and biodiversity restoration) and with engineering options (for salinity mitigation).

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