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A review of options for dryland salinity management in low rainfall agricultural environments in Western Australia.

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Abstract

Currently, there are very few options for salinity management in low rainfall environments (less than <350mm annual rainfall). The challenge for salinity management in traditional farming systems, is to balance the profitability of annual crop based systems with sustainable high water using options and engineering solutions. This paper reviews literature on the potential profitability and water use of two developing perennial plant based systems (oil mallees and saltland pastures) and deep drainage, and the trade-off between water use and profitability objectives within these options as potential salinity management techniques.

Introduction

In Western Australia where over thirty percent of the State's cleared agricultural land is threatened by dryland salinity, with thirty six per cent of the total area threatened being located in low rainfall (less than 350mm) areas. (Natural Resource Assessment Group, Department of Agriculture, Western Australia).

Low rainfall agricultural areas are a challenging environment for dryland salinity management given the lack of options available, the predominance of annual crops and pastures and the small profit margins per hectare often experienced.

Early salinity prevention research has focussed on high water use commercial tree plantings in high rainfall environments and deep rooted perennial pastures in certain medium rainfall areas.

However, George et al (1999b) noted that in many areas, current high water use vegetation and perennial options may only delay the onset of salinity and not necessarily change the overall area of land affected by salinity. In this case, enhanced discharge management utilising engineering options like deep drains, may be the only feasible option to restore saline land to production. Otherwise salinity management will evolve to "living with salt" by planting salt tolerant crops and pastures.

The following is a review of technical and economic literature on the main salinity management options for the low rainfall agricultural environment of Western Australia. Three options are considered: oil mallees, saltbush and deep drainage. This paper offers conclusions on the roles of these options in salinity management in low rainfall environments.

Saltbush

Production research:

For a number of years Australian farmers have tried to control waterlogged saline land with trees and a wide variety of salt tolerant plants to support grazing industries. However the available technologies for selection, adaption, establishment and management, together with the production economics of such systems, are not known with any certainty.

Early research on saltland pastures in Western Australia in the late 1980s (Malcolm et al, 1988; Malcolm, 1986) supported the view that adult sheep, grazing saltbush stands could make live weight gains. Malcolm and Pol (1986) reported that sheep made modest live weight gains initially (for approximately the first 500 sheep grazing days per ha) and then maintained or slightly lost condition over the next 120 sheep grazing days per ha. They recorded that the yields of forage from Atriplex spp. grown in Western Australia on soils too saline for cereal cropping, averaged 5 t/ha dry matter in areas receiving about 500mm annual rainfall in a Mediterranean type climate.

Malcolm (1988) studied the influence of plant spacing on Atriplex spp. production and concluded that smaller Atriplex spp. varieties like Atriplex vesicaria (bladder saltbush) yielded less on a per ha basis when planted at spacings wider than 1 x 1m. By contrast larger shrub varieties like Atriplex amnicola (river saltbush) yielded the same on a per ha basis when planted at spacings varying from 1 x 1m to 3 x 3m. As a result of these early research findings, a national group was established in the late 1980s with the aim of promoting productive saltland pastures (Productive Use and Rehabilitation of Saline Lands -PURSL).

In 1996, the research of Warren and Casson questioned the value of saltbush as a fodder plant. Their 4 year grazing trial in the mid 1990s indicated that the initial weight gain that occurred with sheep on Atriplex spp. (saltbush) pastures, should more correctly be attributed to their increased water intake to compensate for their high salt diet. They concluded that saltbush usually provided between 20-25% of the total feed on offer, and that once the herbaceous understorey was consumed, the animals lost weight.

Research estimates of sheep feed intake from saltbush have been variable with feed production from saltbush being influenced by soil salinity, soil fertility, planting methods, spacing and plant genotype (Barrett-Lennard, 1993). Feed production estimates range from 0.48kg DM/day (Warren and Casson, 1994) to 2.0kg DM/day (Le Houreou, 1992; Malcolm et al, 1988). Malcolm et al(1994) trialled a number of halophytes to test their salt, waterlogging and inundation tolerance. (see Table 1.)

Table 1.Species performance against a range of criteria

	Species							
Criteria	A.am	A.un	A.le	A.bu	A.pa	A.nu	A.ci	M.br
Essential								
Survival	++	+	+	+	+	5	+	+
Grazing recovery	++	+	+	-	-	+	?	+
Seed production	+	+	+	+	+	+	+	+
Productivity	+	+	+	?	+	?	+	+
Establishment Ability	+	+	+	+	+	?	+	+
Desirable								
Volunteers	1	+	+	+	+	-	+	+
Seed technology	+	++	+	?	?	+	?	+
Feed quality	+	+	+	+	+	+	+	6

Palatability	+	+	+	-	+	-	+	+
Optional								
Growth habit	++	++	4	-	++	-	++	+
Shelter	2	3	+	+	-	+	-	-
Soil conservation	+	+	-	+	+	-	++	+

Source: Malcolm 1994

A.am = Atriplex amnicola: A.un = Atriplex undulata; A.le = Atriplex lentiformis;

A.bu = Atriplex bunburyana; A.pa = Atriplex paludosa; A. nu = Atriplex nummularia

A.ci = Atriplex cinera; M.br = Maireana brevifolia.

Ratings are: ++ excellent, + good, - not satisfactory

1.Selected lines have good volunteering ability; 2.Genotypes ranged from erect to prostate.

3.Moderately grazed bushes develop sufficient height to protect sheep from cold winds.

4.Bushes are open and reach 2m in height. Farmers tend to favour this species.

5.Long term survival in W. Aust. was poor; 6.Contains 6-12% oxalate- but high in protein

Malcolm reported that for areas receiving 300-400mm of annual rainfall, the sheep carrying capacity of saltland pastures in the summer/autumn period ranged from about 180 sheep grazing days (SGD) per ha for samphire (Halosarcia spp.) on highly saline and water logged land to 2200 SGD ha for stands of Atriplex spp. and Maireana brevifolia (Bluebush) on less severely affected areas.

Malcolm et al (1994) noted anecdotal evidence of farmers that suggested that the wool produced from sheep grazing on halophyte forage shrubs was cleaner, finer and of more even fibre diameter than wool from sheep consuming dry feed and grain supplements.

However, research by Warren and Casson (1996) on the value of Atriplex spp. for sheep production indicated that the condition of sheep on saltbush pastures was no better than the condition of sheep on dry pasture. This research finding had a negative effect on the further promotion of Atriplex spp. as a pasture, and many saltland pasture research projects in Western Australia stopped at this time.

Casson et al (1996) followed up earlier research by Warren and Casson (1994) and Warren (1995) and made similar conclusions about the value of saltbush. It was considered, at best, a maintenance feed for dry sheep. They concluded that stubble components were a major part of the daily feed intake of the sheep in their trials, with animals gradually moving onto the less digestible saltbush fodder as the supply of the better quality understorey species was exhausted. In this study they also concluded that there was a possibility that saltbush may supply nitrogen that allows animals to better utilise other poor quality dry feed roughage.

Morcombe et al (1996) studied sheep production on saltbush pastures (bluebush) in three consecutive autumns in the north-eastern wheatbelt (Pithara) of Western Australia and concluded that saltbush plantations could be used to provide a feed source to partly fill the autumn feed gap for dry sheep. They recommended the removal of sheep from the saltland pastures before their mean live weight values declined, to prevent low staple wool strength. They suggested that saltbush stands could be made both more economically viable and productive with the inclusion of winter-active plant species within the saltbush stands.

Lloyd (1996) noted the improvements on his farm as a result of saltbush pastures with increases in farm carrying capacity from 3000 sheep to 4000 sheep with a stocking rate on saline land of 5.2 DSE/ha/yr (dry sheep equivalents) compared with a stocking rate of 3.0 DSE/ha/yr on his non-saline pastures over the 1993-4 summer period.

Hopkins and Nicholson (1999) researched the meat quality of lambs in New South Wales grazed on either predominantly saltbush (Atriplex nummularia) and supplemented with pasture hay/oat grain and compared them with lambs grazed predominantly on lucerne (Medicago sativa). The research noted lower live weight values for carcasses from the saltbush/hay group. However no differences in meat quality (flavour strength, tenderness and juiciness) were noted between the groups.

Recent and on-going research by Norman et al (pers comm.) reviewed and modelled animal production on saline land in the eastern wheatbelt of Western Australia, in terms of plant quality, animal performance (Grazfeed analysis) and plant selection by sheep grazing salt tolerant pastures. Their early results indicate that sheep at all three trial sites gained weight and increased condition during the 3 month summer/autumn grazing trial.

Water use research:

Malcolm (1994), in discussing the water use potential of saltbush pastures, noted the need to keep saltbush shrubs a certain size to maintain the required leaf area index (LAI) for consistent water use. Malcolm (1998) also studied the influence of plant spacing within saltbush pastures on potential water use.

Field research on salt accumulation data collected by Barrett-Lennard and Malcolm (1999) for Atriplex spp. pastures in Western Australia suggested that pastures used 60-100mm (30-5mm/year)of groundwater over the 2 year study period. They concluded that in situations where removal of in-situ vegetation is the main cause of salinity, the planting of perennial halophyte shrub pastures may prevent annual recharge further contributing to the problem by the use of all of the incident water (rain and run-on).

However, Slavich et al(1999) noted that the transpiration rates of oldman saltbush (Atriplex nummularia) in a 4 year study in Wakool, NSW was very low and concluded that the plants were having a negligible impact on the watertable.

Lefroy (2000) also suggests that saltbush water use at low production levels (<0.75 t/ha/yr) would be negligible given that leaf area is removed by sheep at a time of year (the autumn feed gap) when transpiration is potentially high.

Economic research:

Malcolm (1986) noted the potential economic benefit of perennial pastures, in moderating the fluctuations in pasture feed supply, in particular noting the benefits of saltbush in extending a property's stock carrying capacity over the summer autumn feed gap. Salerian et al (1987) modelled saltbush production using data of Malcolm and Pol (1986). He reviewed the economics of saltbush pastures and suggested that saline pastures were a profitable alternative to the conventional practice of maintaining sheep on dry pasture and grain supplements in the summer/autumn period.

Lefroy et al (1992) noted that the economic value of fodder shrubs depended on a number of factors including:

-the cost of establishing and managing the shrubs

-the time taken for them to reach a productive age

-the persistence of the plant under regular use (annual regrowth and longevity)

-the ability of the plant to produce feed when it is needed most.

Bathgate (1993) also indicated that establishing saltbush pastures for annual production could be profitable, although at low levels of production (<0.4t/ha) saltbush pastures were unlikely to be economic. Malcolm (1994) suggested that the economic value of saltland forage should be assessed in terms of whole farm animal production where halophytic shrubs are best utilised in combination with dry residues especially during the summer/autumn feed gap. He concluded that the costs saved on hand feeding grain to sheep by using halophytic pastures, was around $US66/ha which compared favourably with the net return from growing wheat on nearby non-saline land. Malcolm (1996) also reported anecdotal evidence suggesting that a kilogram of feed in the autumn feed gap has 14 times the value of a kilogram of feed in the spring in Western Australia.

Lloyd (2001) reported a gross margin of $76/ha from saltbush pastures in the eastern wheatbelt (325mm annual rainfall) of Western Australia, due to the increased stocking rate on his saltland pastures from 2 DSE/ha on balansa (Frontier) clovers to 8 DSE/ha with saltbush pastures (Atriplex spp. and balansa clovers).

Bathgate and McConnell (2001) noted that the economic performance assessed by modelling saltbush pastures was greatly influenced by the assumed levels of dry matter production (varying from 0.4 - 0.8t/ha), its invitro-digestibility (7.5Mj/kg) and prevailing wool prices. They suggested that it would be difficult for saltland pastures in Western Australia to out-perform the $50/ha/year (at Jan 2001 wool prices) being achieved by typical clover/medic/grass pastures. They concluded that saltland pastures may however be economic in providing feed during the summer/autumn feed gap where they are more likely to generate sufficient income to cover the costs of saltbush establishment and maintenance and a generate return on the farmers' investment.

Oil mallees

Perennial woody 'crop' planting has been identified as a potential option for dryland salinity management in Western Australia. Oil mallee eucalypts are seen as a viable option, particularly for low rainfall environments. Oil mallees as potential woody perennial crops have been under development in Western Australia since 1993. Since then over 20 million mallee seedlings have been planted by over 900 growers. (J.Bartle pers comm.)

George et al (1997) noted that non-commercial perennial plantings will not be implemented by farmers on a scale large enough to ‘solve the salt problem’. For this reason there has been considerable focus on the development of commercial tree crops like oil mallees and pines for integration into farming systems. George et al (1997) surmised that dryland salinity management without commercial perennial tree crop options, will require community financing of tree plantings on either a massive scale or to a lessor extent, strategically focussed on protecting priority assets such as water resources or native reserves.

Considerable research continues on the development of new low cost production techniques for harvest and processing of mallee crops. Uses for the wood fraction from mallee biomass have been developed after early analysis showed that eucalyptus oil alone would not be commercially viable (Bartle et al, 1996; Cooper et al, 2001). Potential uses of the wood fraction include activated carbon, renewable energy (using wood and other residue as fuel), industrial paper and panel board. Integrated (multiple product) processing brings further economies. A feasibility investigation in WA has shown that integrated processing to concurrently produce activated carbon, eucalyptus oil and electricity would be commercially viable (Enecon, 2001). This approach adds considerably to the potential commercial of mallee crops.

The establishment cost and opportunity cost of forgone production on land occupied by tree crops imposes an economic constraint on the rate of adoption of trees like pines and commercial eucalypts. However shorter rotation woody crops like oil mallees provide earlier revenue return and investment payback than the 30 year rotations of eucalypts or Maritime pine for sawlogs (Bartle 1999).

In addition oil mallees also provide a high water use advantage in the management of on farm salinity. Bartle (1999) notes that belt plantings of oil mallees offer the opportunity for broader scale adoption of woody perennials across the farm providing both higher water use potential and the integration of the oil mallees into alleys allowing inter-cropping with traditional cereal production systems between the belts.

Production research:

Early studies on oil mallee growth, oil production and water use on a range of potential species have been carried out at a number of sites in Western Australia (Eastham et al, 1994; Eastham et al, 1993). In New South Wales, Milthorpe et al (1994) investigated the influence of harvest timing, fertiliser application and species biomass on oil yield variation. Until recently little research was conducted on the influence of soil type, tree age and harvest schedules on oil mallee production (Wildy et al, 2000a).

Wildy et al(2000a) studied two different (summer and winter) harvest regimes across 9 taxa of oil mallees in the wheatbelt of Western Australia. They found that biomass production from the first harvest was strongly correlated with water availability and sapling size at the first cutting (beyond 3yrs of age). Like similar studies by Milthorpe (1994) and Hingston (1994), the study showed no evidence of soil fertility influencing production, with water availability having more influence on growth and production.

Wildy et al (2000a) noted that coppiced trees were sensitive to harsh conditions including the presence of shallow saline groundwater and cold winter temperature conditions during early regeneration. They reported that mallees on saline soils may be expected to show progressively declining productivity if soil salt and groundwater levels were to rise to high levels.

Research in Western Australia has indicated that the harvest regime for oil mallees will range from 3 to 5 years to first harvest with a 2 to 3 year repeat harvest cycle. Low rainfall environments and less productive sites (soil type and saline levels) will require longer delays to the first harvest (5yrs) and greater intervals between subsequent harvests (3yrs) (Herbert, 2000). Wildy et al(2000b) in a 7 year trial compared biomass yield from initial supply cut to the first harvest across a range of soil types in the north eastern wheatbelt of Western Australia.

Techniques of establishment and management of mallees have been greatly refined over the past decade. There are several main species in use and the pooled knowledge of performance now enables accurate selection of species for soil and site type. Initial planting design using belt layouts for interception of down slope water movement and minimum disruption to large scale cropping have emerged (Bartle, 1999).

Water use research:

Oil mallee field research is still investigating the water use effectiveness of various planting strategies on different soil profiles and plantation design profitabilities, with the majority of hydrological research focussed on upper slope preferential recharge zones and salinity discharge areas. In terms of salinity management, it is expected that oil mallee plantings will be useful in both upper slope recharge, sandy soil zones and in wetter valley floors.

Research discussion notes the potential yield penalties on adjacent crops which may arise from oil mallee belts and their deep rooted perennial water use. Data is required so that this can be factored into any economic analysis. This effect may vary with season, being greater in drier than in average years. This effect will also be moderated by regular harvest so that a tree belt/adjacent crop competition balance might emerge. The Oil Mallee Company (WA) and the Salinity CRC will be investigating the effect of harvest and water use/competition effects on oil mallee growth and oil production.

Research by White et al (2000) confirmed that where groundwater is accessible, contour planted belts of trees are an effective means of reducing groundwater recharge with minimal tree-crop competition for water use in medium rainfall areas (445mm). Stirzaker et al(1999) modelled optimal planting densities for the control of rising water tables in a paddock scale water balance study. They concluded that contour-planted tree belt designs achieved recharge management objectives whilst minimising tree-crop competition over significant areas.

Rundle and Rundle (2001) note the value of belt plantings in preventing seasonal waterlogging, controlling wind erosion, providing stock shelter and as an insurance against the future threat of salinity.

Ward et al (2001) estimated water balance (change in soil water storage) in a 5 yr rotation of clover pasture (3yrs), wheat (1yr) and canola (1yr) and predicted there would be annual recharge of 35mm. For the same period they estimated that drainage beyond the root zone could be nearly halved to 18mm by replacing the clover with lucerne grown at optimum specifications. They further predicted that to reduce recharge to 5mm/year, 16% of the farm must be occupied by 8m wide tree belts (if the rest of the farm is in pasture rotation with crops) or 8% of the farm area (if lucerne is planted in rotation with crops). They noted that the robustness of their recharge estimates depends on the accuracy with which soil evaporation, interception, transpiration and change in soil water content were estimated. The study by Ward et al(2001) demonstrates the technical feasibility of controlling recharge using contour planted tree-belts with perennial pastures in a phase farming system where trees have access to fresh groundwater and shallow regoliths in medium-high rainfall areas.

Economics research:

An economic assessment of oil mallee production has been examined in a number of studies including Cooper (2001), Herbert (2000), Enecon (1999) and Bartle (1996). To date the profitability of oil mallees has only been estimated within the context of the investigations conducted in the Integrated Mallee Processing (IMP) feasibility study (Enecon, 2001). The harvest and handling costs estimates in this investigation appear sound but the required systems have not yet been developed.

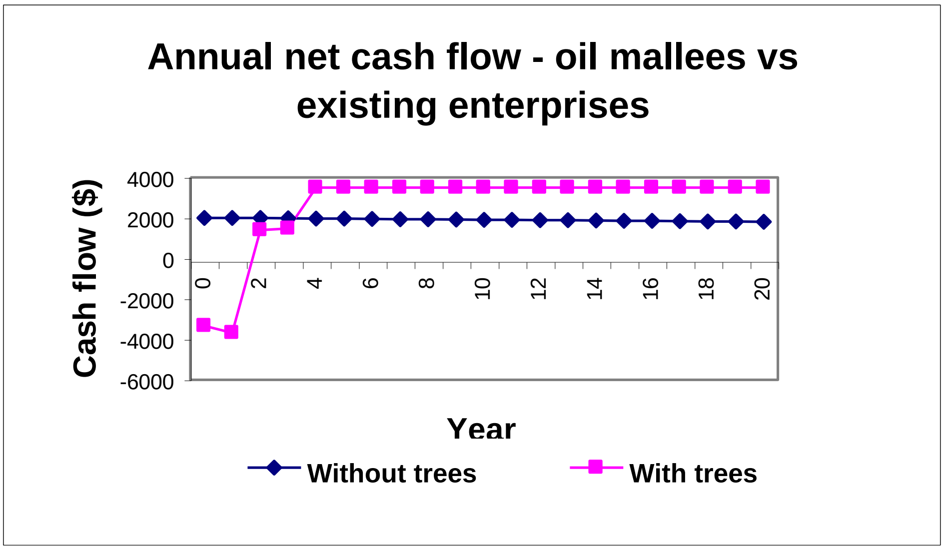
A recent study by Cooper (2001) reported that the commercial development of oil mallees must include integrated processing ie: the concurrent production of eucalyptus oil, electricity and activated carbon (or other wood products) from mallee feedstocks. Cooper indicated that a large scale industry relying solely on eucalyptus oil production is unlikely to produce oil at a price low enough to ensure entry into the bulk industrial solvent markets. He concluded that integrated processing should give farmers a higher return on mallee production allowing for broader scale application of mallee planting and the parallel potential benefits of higher water use.

Early profitability estimates by the Department of Agriculture in Western Australia, on oil mallee production in a medium rainfall environment (450mm) indicated that planting 15% of the paddock to oil mallees appears to be a profitable option with harvest production of 15kg/tree from the first harvest at 4yrs and then every second year thereafter with a gate price of $15/t (Holt and Menzies, 2001). Given these returns, a 10,000 plant oil mallee planting modelled over 20yrs (spread over 25ha at a 15% planting density) would result in a gross margin of around $270/ha/yr with establishment costs repaid in 10 yrs and a benefit to cost ratio of 1.12 to 1. However, this BC analysis does not include the opportunity cost of production of land planted to mallee belts. Bartle (1999) notes the economic significance of mallees is considerably enhanced with the inclusion of salinity management benefits such as high water use, potential recharge reduction, improvements in soil erosion and reductions in water logging and inundation on adjacent crop production.

Herbert (2000) outlines a number of factors that influence oil mallee profitability including:
-area covered and planting density (15-25% of the area)
-costs of planting (45-55cents/tree planted)
-time of harvest (first harvest 3-5yrs, subsequent harvest 2-4yrs)
-biomass harvested per tree (15-20kg/tree)
-revenue ($30/t of biomass delivered to the plant)
-costs (contract harvesting and cartage $15/t)

Herbert concluded that under current 'best-bet' scenarios, oil mallees in a 4/2 harvest regime returning $15/t biomass on farm will be profitable for those farmers with production values pre-oil mallee planting of $79/ha or less (see Table 1). The analysis showed that for lower tree yield areas (acid sands and lower rainfall areas) with a 5/3 harvest regime, oil mallees are only likely to be profitable if current production values are around $10/ha or less. Ongoing research in Western Australia is suggesting that economies can be achieved from later and heavier, less frequent harvests in low rainfall areas (J.Bartle pers. comm.)

Table 1.



Source: (Herbert 2000)

Herbert did not include any additional salinity management benefits in his economic analysis, further research should indicate that tree planting distribution can be designed to improve water use and ameliorate reduced crop yields.

<u>Deep drainage research</u>

It is generally agreed that deep drainage does not address the root cause of salinity – that of water table recharge – it can however influence farm productivity and salinity management in a number of ways including: the lowering of water tables, a reduction in waterlogging area and duration, removal of surface run-off (particularly in relation to episodic rainfall events) and the return to productivity of land adjacent to the drain (Taskforce, 2000).

Given the scale of salinity and the slow rate of response of the landscape to water balance changes in Western Australia with vegetative management options (George et al, 1999b), drainage is often seen as a salinity management 'quick fix' (Ali and Coles, 2001).

In the wheatbelt of Western Australia the critical depth to the water table to avoid the impacts of saline groundwater on crop growth is around 1.5-2.0m (George, 1985; Nulsen and Baxter, 1982). The principal aim of deep drainage (sub-surface drainage) is to lower the watertable usually to within 2m of the surface. In addition to lowering groundwater tables, drains also assist in preventing additional accumulation of salts through capillary rise and evaporation of groundwater and by allowing rainfall to leach accumulated salts out of the upper soil profile into the drains for removal into natural drainage lines (where permitted) or evaporation ponds. These processes have the potential to reclaim areas affected by secondary salinity and waterlogging.

In Western Australia, deep open drains have been used as a sub-catchment salinity management tool for over 20 years. In other states of Australia, surface drainage systems are more prevalent (shallow drains) particularly in irrigation areas. These surface drains allow the removal of excess run-off that would otherwise pond and cause water-logging and eventually recharge to the groundwater. In addition, where the groundwater is saline, surface drains may reduce soil salinity levels (SKM, 2001).

In their report to the NDSP (National Dryland Salinity Program), SKM consultants concluded that research and literature on engineering options for dryland salinity management in Australia was poorly documented with the most recent research being conducted in Western Australia (SKM, 2001).

Ali and Coles (2001), suggest that this lack of published research is due to the vast volume of global research on deep drainage being focussed on irrigated land drainage and wetlands drainage and the associated salinity issues, rather than the drainage of dryland salinity agricultural areas affected by rising shallow saline groundwater tables. Furthermore, the lack of formal evaluation of engineering options at variable scales has generated intense discussions and at times conflicting interpretation regarding the effectiveness of engineering solutions for salinity management (Ali and Coles, 2001).

George (pers comm.) notes a recent and significant change in status has been afforded to drainage especially in Western Australia, with increased focus on engineering works in the State Governments Salinity Strategy in 2000. This change reflects an increasing awareness of the relative impact of recharge based options (slow and few practical options available) and an increasing demand for engineering options in valley floor areas. George (1999a) surmises that the use of engineering options in salinity and water management was lost in the 1980s with the Landcare preference for tree planting.

Whilst in some parts of the agricultural landscape in Western Australia, salinity may be controlled or seeps reclaimed by reductions in recharge, there are equally as many, or more, landscapes where recharge management techniques will not be time or cost effective even in the medium term. George et al (2000) in their Flowtube water balance modelling assessment of a number of catchments in Western Australia concluded that the relatively flat catchments in the zone of ancient drainage, in the low to medium rainfall areas in the state, representing over 60% of the region, only respond to significant reductions in recharge. Lower levels of intervention buy a significant amount of time in catchments with an existing deep watertable, but do not significantly alter outcomes in the longer term (300 years). By contrast, modelling suggests that catchments in undulating rejuvenated drainage landscapes respond to the recharge reductions relatively quickly. In these areas, groundwater and salinity levels may decline after intervention in the medium to long term.

As a consequence, George predicts an increasing prominence of engineering salinity management strategies, particularly for landholders whose land is saline, has shallow water tables or significant periods of waterlogging. Pen (2000) concludes similarly, given that recharge and high water use options alone cannot be carried out at a scale sufficient to deal with the expanding momentum of salinity in many catchments. 'Artificial drainage' or 'enhanced natural drainage' is increasingly looked upon as the only viable solution to cope with the new hydrological regime that is presenting itself in many areas.

Production research:

A number of deep drainage research reports in Western Australia note mixed success in terms of the reduction in salt affected areas reclaimed through sub-surface drainage. Many reports indicate that reductions in salt affected areas were limited to land close to drainage lines (Ferdowsian et al, 1997; Speed and Simons, 1992).

Speed and Simons (1992) concluded that deep open drainage was not very effective, with the success of deep drains in any particular landscape depending on:

- the permeability and/or transmissivity of the top layers of the adjacent soils and
- the hydraulic gradient available to move water into the drain.

Drainage performance summary research in south western Australia by George and McFarlane (1994), unlike Speed and Simons (1992), confirmed that drains can be effective in lowering water tables adjacent to the drains and reducing soil salinity levels where soil permeability and transmissivity levels are high.

Ferdowsian et al (1997) also reported in their deep drain case study in the south-west of Western Australia, that salinity had been reduced and land had been recovered up to 200m away from the drain.

Coles et al (1999) studied 25 deep drainage sites in the south west of Western Australia and reviewed deep drainage performance in terms of position in the landscape, soil type, effect on waterlogging and salinity, cost-effectiveness and off-site impacts. They reported that in terms of a reduction in waterlogging and improvement in crop growth, drains placed at the break of slope were the most effective with drains installed on flat low lying areas like valley floors, having highly variable impacts on both salinity and waterlogging levels with limited increases in crop yields.

They noted that deep drains could reduce watertable levels near the bottom of the drain and could drain up to 100m either side of the drain under ideal conditions and as little as 10m either side of the drain in soils with poor hydraulic conductivity. They concluded that open drainage may not be the 'most appropriate, cost effective method of managing salinity' and that landholders may believe drainage is successful by virtue of the reduced waterlogging and salinity experienced in spite of not recovering the cost of the drain.

Coles et al (1999) reviewed both changes to the water table and crop yields (anecdotal evidence). They reported that in the case studies examined, the drainage zone extended between 25 and 90m from either side of the drain dependent on soil type.

Recent anecdotal evidence reported by R.George (pers.comm.) from deep drainage reports in the eastern wheatbelt of Western Australia indicate water table impacts of at least 100m from the drain, and in some cases cropping has resumed in previously saline areas. George confirms that these positive results are greater than theoretically predicted and could be influenced by the greater flows coming from deeper drains and the drains being situated in highly permeable soils (>0.5m/day).

In addition, George (1999b) noted that improvements in salinity management through the use of deep drains may also be attributable to a number of other factors including: the interception of a hillside seep, soil salt leaching, reduced input to soil salt levels, reductions in waterlogging, a reduction in near surface flow, reduced inundation, improved lateral flow reducing or eliminating the effect of perched water tables in duplex soils, in addition to reductions in groundwater levels. In this respect the improvements associated with deep drainage will vary from site to site.

Coles and Prince (2001) highlight the difficulty in comparing deep drainage technical research given the lack of common methodology used in the examination and assessment of deep drains. They suggested that further analysis needed to be provided on measurable performance criteria such as crop yields or soil and groundwater solute measurements and a systematic evaluation approach in order to compare drainage studies more objectively.

Water'use/removal' research:

There is little published research currently available on both quantitative and qualitative assessment of water removal by deep drains. Anecdotal evidence by drainage contractors in the wheatbelt of Western Australia suggests water removal rates between 0.03-0.5L/s per km of drain (K.Lyons pers comm.). However these measurements are difficult to attribute directly to drainage water removal given the interconnectivity of other benefits associated with drainage which may also be contributing significantly to water removal and hence salinity management.

Coles et al (1999) also noted that the estimation of 'water use/removal' benefits from deep drains was constrained by hydrological theory which relies on the assumption that soils within a catchment are homogeneous. They noted soils in the valley floors of the eastern wheatbelt of Western Australia are heterogeneous and vary significantly in a short distance both vertically and horizontally. For this reason it was difficult to predict the volume and flow of groundwater into deep drains.

Together with George (1999a) they indicate that whilst traditional hydrological theory suggests that deep drains are unlikely to remove a significant amount of water or affect a large enough area to ensure the viability of deep drainage, groundwater observation wells in Western Australia have indicated that in some cases significant groundwater has been removed. Several related hypotheses have been provided to explain the better than expected performance of drainage groundwater removal on salinity management and include 1) increased lateral flow in the A horizon (better leaching), 2) reduced water logging due to reduced run-on, 3) the removal of accumulated salt deposited by prolonged groundwater discharge and evaporation and 4) macroporosity of subsoil and possible preferential pathways in soils. These preferred pathways are likely to be site specific and current technical knowledge in this area limits further analysis (George, 1999a).

Coles and Prince (2001) note that the relative contribution of deep drains compared with other salinity management options like tree planting, surface drainage and perennial crops is difficult to ascertain in terms of their potential economic return and water use. This is largely attributed to the lack of a consistent and well defined framework for assessing deep drainage.

Coles et al (1999) acknowledge that the spatial and temporal variability of water movement within soil profiles is complex and makes hydrological predictions of water table improvement and water use/removal very difficult.

Furthermore, Penn (2000) points out that current deep drainage research is unable to assess what proportion of salinised land is caused by ponding of additional saline surface water flows brought on by land clearing and that which is attributable to rising groundwater tables. The complex interactions between the connectivity of the soils and the arial extent of salinity are still not yet well understood by hydrologists.

Economic research:

George and McFarlane (1994) noted that drainage is most likely to be cost-effective in situations where the land has high value (towns, nature reserves, infrastructure), the soils and aquifers are permeable and in hydraulic connection and where there is a safe option for saline disposal.

Coles et al (1999) reviewed a number of drainage studies in Western Australia and determined a break-even discounted cashflow analysis which they used as an approximate guide for drainage efficiency. They noted a number of factors which significantly influenced drainage profitability:

-cost of construction

-cost of maintenance

-frequency of maintenance

-number of years after construction that land is reclaimed

-area reclaimed

-increase in average return per ha after reclamation and

-interest rates (opportunity cost)

Their results concluded that deep drains at a cost of $5000/km to construct, need to reclaim a minimum of 5-15ha/km of drain to break even, dependent on the frequency of maintenance programs and the gross margins received on ‘reclaimed land’.

However for the 25 drainage sites examined, the actual extent of the impact of the drain on groundwater tables was generally less than 20m (4ha/km) and rarely exceeded 40m (8ha/km) suggesting that on most sites studied, deep drains were not cost effective based on the estimated returns on the land recovered.

Coles et al (1999) also recommended that allowance be made in any drainage economic assessment for maintenance costs. Green (1990) noted that major deep drainage maintenance would probably be required every 4-5 years and may include repairing low spots in embankments, re- excavating of channels to original dimensions, rebuilding banks and maintaining fencing.

Coles and Prince (2001) noted that the scale of assessment – from farm level to sub-catchment and regional catchment level - must be considered in reviewing both the economics and efficiency of deep drainage.

Ferdowsian et al (1997) measured the economic benefits of deep drains and concluded that using NPV analysis the drain examined was not cost-effective. They recommended that a feasibility study be carried out before the construction of a deep drain and the less costly shallow drains (gradebanks and interceptor banks) be tried first. The economics of gradebanks versus deep drains, has been modelled by Coles et al (1999). The analysis indicated that less than 1 ha/km of recovered land (or 80% less area than for deep drains) was needed to breakeven, owing to the lower costs of construction and maintenance.

<u>The challenges for salinity management in low rainfall environments</u>

Excessive drainage of water beneath the root zone is occurring within most areas of agricultural land using traditional pasture and annual cropping production systems in Australia. Deep rooted (herbaceous and woody) plants like lucerne and agroforestry systems including oil mallees and trees will be required in combination to increase water use. In other areas already affected by salt, salt tolerant perennial systems maybe required to obtain profits from these affected parts of the landscape.

Failure to adjust dryland farming systems will result in continuing rises in water tables and further salinisation in agricultural areas. Research conducted by the Department of Agriculture in Western Australia for the National Land and Water Resources Audit in 1999 provided water balance analysis of current and predicted future land use across the State. The research indicated that in 19 agricultural zones, representing 80% of the state's agricultural area, 16 zones expected recharge reduction of less than 25%. As predicted by George et al(1999), this level of recharge reduction would delay the onset of salinity in a local area, but was unlikely to have any major influence on the eventual extent of salinised land.

These results suggest, that in terms of a future salinity scenario (30-50yrs), a significant portion of Western Australian farmers will either need to enhance their productivity from salinised soils (salt tolerant wheat and pasture species, barley and saltland pastures) or use water movement and/ or water removal options like gradebanks, deep drains and pumps to remove water from the landscape in order to continue more traditional agricultural production.

Engineering options like deep drainage, water ways, W-drains and gradebanks would also be needed in areas where rising water tables, water logging and inundation occur.

In the Western Australian wheatbelt integrated salinity management systems will need to be developed and applied extensively on a broadacre level to mostly low lying flat areas of agricultural production where highly saline groundwater is at or is close to the surface. Saltbush, oil mallees and deep drainage are currently being investigated as sustainable and productive salinity management systems for low rainfall environments. However, a number of profitability and water use challenges exist that prevent broad scale adoption of these options in low rainfall areas. Some of these challenges include:

Saltland pastures:

- The long term sustainability of saltland pasture systems including saltbush in conjunction with salt tolerant annual pastures could be problematic if the saltbush production results in increasing salinity levels in the root zone. Research is still being conducted in this area (Barrett-Lennard and Malcolm, 1999).

- Grazing management of saltbush influences both the volume of forage produced and its nutritive quality. Grazing strategies need to balance the regeneration of forage with the required LAI (leaf area index) to ensure desired levels of water use.
- Research is still determining the critical levels of Atriplex spp. (by species) required to maintain/increase livestock weight in conjunction with annual pastures, legumes, grasses and supplements.
- Further optimal grazing research will help to determine whether the costs of establishment of saltland pastures are justified in terms of animal production performance.
- Malcolm (1999) details some of the difficulties faced in successfully seeding saltbush, with seeds sensitive to weed competition, insect attack, sand blasting, waterlogging, high salinity and frost.

Oil mallees:

- Research is still determining the optimum planting configuration for oil mallees, which will depend on the slope of the site, fresh water availability, soil type and salinity management needs in terms of water use and water interception. Furthermore, plantation designs that reduce competition with adjacent crops need also to be determined (Bartle, 1999).
- Research to date is yet to determine whether the reduction in water table depth under oil mallees extends beyond the area planted. (Anecdotal evidence in Western Australia suggests draw down effects go beyond plantation parameters). Bartle (1999) noted there is little knowledge or research in progress on the processes by which water becomes available to roots, either via natural flow paths or by deliberate management or design of perennial plantings.

Deep drainage:

- Significant challenges for drainage design and construction exist particularly if surface and groundwaters are to be mixed. Furthermore, long term drain stability, downstream impact, water disposal (salt, silt etc) and the problems arising from heavy episodic rainfall events also need further examination.

- Research needs to determine the lateral influence and effectiveness of both surface drains and deep drains in a variety of landscape positions.
- Disposal of saline waters from deep drainage lines into natural creek lines may result in the saline waters killing riparian vegetation and increasing eutrophication, sedimentation and salinity in soils and creeks downstream as well as potentially recharging downstream aquifers (Ferdowsian et al 1997).
- In Western Australia particularly, a poor understanding of water movement within the unsaturated zone of wheatbelt soil profiles significantly complicates any interpretation of the effectiveness of deep drains (Penn, 2000).
- Coles and Prince (2001) note that the off site impacts of deep drainage in Western Australia have not been estimated in any detail. Impacts include:
  -nutrient/pesticide movement
  -sedimentation build up in the drains
  -increases in water velocity and volume leading to erosion and flooding
  -increasing the salt load and hydroperiod of the receiving water body
  -aquifer recharge due to drain leakage/discharge areas transmitting water
  -destruction of the natural ecology of the disposal site

  Coles and Prince suggest that whilst the economic methodology and analysis of such impacts have not been established in research literature to date, these ‘costs’ do need to be considered.

In conclusion, it is increasingly recognised that there is no one solution or management tool to address dryland salinity, water logging and inundation. Options may include revegetation with native or commercial plants including salt tolerant species (eg; saltbush), adopting high water use agroforestry farming systems (eg:oil mallees) and surface/groundwater management (gradebanks, deep drains) (Coles and Prince, 2001).

The economic value of all three options discussed in this paper are considerably improved with the inclusion of the salinity management benefits generated (reductions in water logging and inundation, improvements in productivity on saline land, potential recharge reduction, improvements in soil condition) and their direct influence on future farm income and land value.

Furthermore, research analysis has yet to assess both the quantitative and qualitative environmental benefits (ecological and biodiversity) of sustainable salinity management.

Research is also needed to demonstrate the economics of 'combined systems' and their potential water use for sustainable salinity management in low rainfall areas.

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