Plantations, Farm Forestry and Water

Proceedings of a national workshop, 20-21 July 2000, Melbourne

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Joint Venture Agroforestry Program
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Water and Salinity Issues in Agroforestry No. 7

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Manipulating Catchment Water Balance Using Plantation and Farm Forestry: Case Studies from South-Western Australia

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Three case studies are presented that describe the use of plantations and farm forestry in south-western Australia to tackle the problems of maintaining water supply and overcoming dryland salinity. The approaches we describe have both geographic and temporal components. The case studies are (1) the revegetation of partially cleared catchments with rainfall >600 mm yr^{-1} to protect surface water supplies from salinisation; (2) the recent widespread establishment of *Eucalyptus globulus* (Tasmanian blue gum) plantations on mostly cleared farmland with rainfall >600 mm yr^{-1}; and (3) the extension of farm forestry into lower (300-600 mm yr^{-1}) rainfall areas.

Dryland salinity results from an increase in infiltration and drainage to groundwater systems following replacement of natural vegetation with shallow-rooted annual agricultural plants. Revegetation can restore the hydrological balance, but given the current scale of and increase in salinity in this area, with 6 M ha eventually likely to be affected, this will have to be extensive. Several issues need to be confronted before such revegetation. These include (a) social and economic considerations; (b) integrating the trees with agriculture; (c) resolving technical issues associated with establishing trees on farmland; and (d) the development of economically viable tree crop industries to promote adoption.

Some of these issues have been resolved for Tasmanian blue gums, but in many cases these have been established as broad-scale plantations and the problems associated with integration have been avoided. Potential constraints on the long-term sustainability of the Tasmanian blue gum industry include (a) a reduction in yield with declining rainfall; (b) the ever-present risk of drought in a Mediterranean climate; and (c) the depletion of stored soil water in the first rotation with likely consequences on second-rotation yields. In low-rainfall areas commercial farm forestry options do not yet exist but are required at a scale of 2-3 M ha. Here the challenges are to develop tree-based industries that deliver both profits and environmental benefits.

Introduction

Two of the major issues confronting Western Australian natural resource managers are the provision of water for an expanding economy and the relentless salinisation of water resources, agricultural soils and remnant natural eco-systems. In south-western Australia potable water is derived from two sources: groundwater from aquifers on the Perth Basin and surface water from forested reservoirs on the granitic Darling Plateau. This surface water flows in relatively short streams that originate in catchments with almost complete forest cover and generally with rainfall >900 mm yr^{-1}. Catchments that extend into areas with <900 mm yr^{-1} or have any substantial area of cleared agricultural land are invariably affected by salinity. The link between land clearing and salinity is well established (Wood 1924; Schofield 1992).

As well as threatening the quality of water from key catchments, dryland salinity currently affects 1.8 M ha of Western Australian farmland, a figure projected to increase to 6 M ha in the absence of intervention (Ferdowsian *et al.* 1996). Moreover, salinity threatens remnant natural ecosystems and rural infrastructure and increases the risk of flooding. It is estimated that 480 species might become extinct in the south-west of WA as a result of salinity (pers. comm., G. Keighery, CALM).

Plantations and farm forestry have the potential to restore the hydrological balance, to ensure sustainable supplies of fresh water and minimise the extent of dryland salinity (Schofield 1992). We define plantations in this context as broad-scale revegetation irrespective of previous land-use. Farm-forestry is where an attempt has been made to integrate the revegetation with agriculture. While it is clear that revegetation is needed for sustainable land management (Shea and Bartle 1988) the investment needed is massive. Although the task is daunting, a range of approaches has encouraged investment in farmland revegetation (Shea and Hewett 1997).

In this paper we use three case studies to review the use of plantations and farm forestry in south-western Australia to tackle the problems of maintaining water supply and managing dryland salinity. These are:

(a) The revegetation of specific, partially cleared catchments with rainfall >600 mm yr^{-1} to protect surface water supplies from salinisation.

(b) The recent, more widespread revegetation of agricultural land in areas with rainfall >600 mm yr^{-1}. In particular, we describe the rapid expansion of *E. globulus* plantations on farmland, review the soil and climatic factors controlling growth, and outline several future challenges that may confront this industry.

(c) The current developments in extending farm forestry into areas with rainfall <600 mm yr^{-1}. Here, salinity is most extensive and the major challenge is to develop new, profitable tree-based industries and encourage integration of trees into agricultural systems over large areas.

We do not consider cases where plantations have been managed to maintain recharge over groundwater supply areas, as this has been well described elsewhere (see for example Butcher 1979). Although the paper has a Western Australian focus many of the themes are relevant to issues elsewhere in Australia.

Physical environment of south western Australia

Land use and climate

South-western Australia has a Mediterranean environment, characterised by a predominance of winter rainfall and an annual summer drought. The annual rainfall ranges from 1400 mm in the south-western corner to around 250 mm at the limit of agriculture. Similarly, annual pan evaporation varies from 1200 mm on the south coast at Albany to 2600 mm at Geraldton, near the northern extent of agriculture (Luke *et al.* 1987).

The area developed for agriculture comprises 18 M ha of the total land area of 24 M ha. The remainder comprises natural vegetation systems, managed either for wood production or as conservation reserves. Much of the farming of this area is reliant on annual rainfall, with dryland farming systems comprising rotations of wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) or grain-legume (*Lupinus angustifolius*) crops and annual subterranean clover (*Trifolium subterraneum)* or blue-lupin (*Lupinus consentinii*) pastures.

Geology and geomorphology

The geology and geomorphology of south-western Australia has been reviewed (Geological Survey of Western Australia 1990). For the purposes of this paper, we consider two major types of terrain each characterised by distinct hydro-geological systems:

Granitic terrain: The region is dominated by the Archaean Yilgarn Craton, and adjacent Proterozoic zones, which extend approximately 400 km north-south and over 600 km east-west, and are mainly comprised of granitic basement rocks. Dolerite dykes have often intruded the Archaean granites, but these are of limited total area.

Sedimentary terrain: The Yilgarn Craton is bounded to the west by the sedimentary Perth Basin. The surface expression of Perth Basin is the 20-30 km wide and 300 km long Swan Coastal Plain, which is comprised of a series of remnant quartzose beach ridges, alluvia associated with rivers, and the Victoria Plateau, which lies between the coastal plain and the Yilgarn Craton. The Plantagenet Beds comprise a range of Tertiary sediments that occur as a thin veneer over the southern margin of the Archaean and Proterozoic basement, extending from Northcliffe to Esperance, and up to 50 km inland.

Both granitic and sedimentary rocks have been strongly weathered, possibly under a previous tropical climate, resulting in deep weathering (laterite) profiles often 30-50 m deep and a surface cover of sands and ferricrete gravels (Mulcahy 1973). Together this material is described as regolith. Along the western and southern margins of the Yilgarn Craton, drainage lines are prominent and the regolith has been variably stripped, the extent depending on the local drainage patterns. In some river valleys, the regolith has been completely removed and basement rock exposed, whereas in other valleys only partial removal of the regolith has occurred. In inland lower-rainfall areas the drainage lines are less competent and landscape stripping is less complete than at the western margins. Here the gently undulating landscapes comprise deeply-weathered materials and their weathering products (Mulcahy 1973).

Hydrogeology and salinity

The regolith encompasses several interacting aquifers often including a shallow, seasonally perched system, a local semi-confined aquifer and a deeper confined regional system (George *et al.* 1997). The regolith also contains a store of salts derived from rainfall (Hingston and Gailitis 1976). These salt stores tend to increase from 100 t ha^{-1} (to bedrock) on the western edge of the

Yilgarn Craton to ~1000-10 000 t ha^{-1} in inland areas (Schofield and Ruprecht 1989).

Under natural vegetation, where most annual rainfall is utilized by the vegetation, the level of permanent groundwater in the profile is low and the salt store is relatively immobile. Conversion to shallow-rooted, annual agricultural plants has profoundly changed the water balance of the landscape. Annual water use by vegetation has decreased as growth and water use are confined to the low evaporative conditions of winter to spring, resulting in leakage beyond the shallow root-zone of annual plants. Furthermore, the annual plants do not utilise irregular summer rainfall. Estimates of leakage of water from the agricultural systems range up to 200 mm yr^{-1} (Johnston 1987), with a value of around 25 mm yr^{-1} regarded as average (George *et al.* 1997). Increased groundwater recharge and rising groundwater tables result in the mobilisation of stored salt and its redistribution towards the soil surface.

Case Study 1: revegetation of surface water catchments

The Helena Catchment

The Helena Catchment (in the Darling Plateau 30 km east of Perth) was dammed with the Mundaring Weir in 1903 as part of a scheme to provide water to Kalgoorlie, 550 km inland. The catchment occupies an area of 1490 km^2 and has an average annual rainfall ranging between 600 and 1100 mm. Consecutive dry years in 1902 and 1903 reduced catchment yield and in an attempt to maintain the water supply from the reservoir, trees were ringbarked. Although stream-flow increased, turbidity increased and reservoir salinity rose to 550 mg L^{-1}. To remedy the situation, regrowth forest was allowed to develop and *Pinus radiata* plantations were established; turbidity and salinity levels in the reservoir slowly decreased (Stokes and Batini 1985).

Agricultural clearing commenced in 1948 in the 5% of the catchment in private ownership, with half this area cleared by 1978. State-owned forest was also cut extensively to supply charcoal from 1960 onwards. In the latter half of the 1960s, stream salinity in the main tributary draining the northern half of the catchment started to increase, reaching annual average values of 1000 to 2000 mg L^{-1} by the mid 1970s. Further clearing was controlled by legislation in 1978. The Government purchased mostly forested, private land and the cleared parts were revegetated. Since 1978 30% of the cleared area has been revegetated. Hydrological analysis indicates that reductions in stream salinity following revegetation occur 10 - 12 yr after the revegetation. Salinity is currently ~1200 mg L^{-1} but the current rate of decrease of 15 mg L^{-1} yr^{-1} may not be sustainable without further revegetation.

The Collie Catchment

The Collie Catchment occupies 2830 km^2 and annual rainfall ranges from 600 in the east to 1300 mm in the west. Half of the 100 000 ha of freehold land in the catchment was cleared of native vegetation before the Government legislated to control the release of Crown Land (1961) and to control native forest clearing (1976). As a result, salinity of the Collie River upstream of Wellington Reservoir was increasing at a rate of 42 mg L^{-1} yr^{-1} (Schofield *et al.* 1988). It was estimated that if no further action were taken, salinity would rise to a flow-weighted mean value of 1500 mg L^{-1}. Large-scale acquisition of private land and revegetation of the catchment commenced in 1979. To date, the Government has planted 6740 ha and private owners have replanted additional areas.

In the mid-1970s, a series of five experimental catchments was established within the Collie Basin to determine the processes causing salinity (Williamson *et al.* 1987). Treatments included the clearing of native forest in catchments in contrasting rainfall zones with 1200 mm yr^{-1} and 800 mm yr^{-1}, and comparing groundwater responses in these areas with uncleared controls. Groundwater and stream-flow of the planted areas were monitored in addition to stream-flow and salinity of the major tributaries. This work (Holmes and Talsma 1981; Peck and Williamson 1987) demonstrated the strong association between land clearing and salinity and provided details of the local influences of vegetation type, preferred pathways and soil properties on catchment hydrology. It has led to an improved understanding of salinity processes and provided data to underpin rehabilitation strategy.

Reforestation Trials

During the late 1970s and early 1980s, experimental trials in both catchments were established to quantify the effect of revegetation strategies on groundwater levels and stream salinity (Bari and Boyd 1992). The sites in the Helena catchment (Flynns Farm), the Collie catchment (Stenes) and Maringee Farms can be categorised into four groups; lower slope and discharge plantings (35% of cleared area revegetated), wide-spaced plantations (54%-57% revegetated), strips and small blocks strategically placed near streamlines and seeps (8% and 14% revegetated) and dense plantations (54%-70% revegetated). Measurement of groundwater levels, stream-flow and salinity indicate that the reduction in groundwater levels depends primarily on the area of trees planted and crown cover rather than the particular revegetation strategy (Bell *et al.* 1990).

The studies have demonstrated the difficulties associated with optimising the relationship between water yield and water quality. In low-rainfall areas, clearing releases salt from the regolith to streams. Revegetation may not halt the mobilisation of salt but does reduce the rate at which salt is discharged into downstream waterbodies. In contrast, in high-rainfall areas the regolith is less saline and revegetation can decrease the yields of non-saline water. Understanding the catchment processes, and in particular the sources of salinity (both in terms of salt concentration and load), has allowed catchment remediation to be targeted to where it will be most effective, rather than using a generic approach across the whole catchment.

Case Study 2: revegetation of farmland in the >600 mm rainfall zone with Tasmanian blue gums (Eucalyptus globulus)

Clearing is extensive in the >600 mm yr^{-1} rainfall zone and salinity more widespread. Despite an expectation that tree planting could restore an appropriate hydrologic balance, tree planting was limited (Shea and Hewett 1997). Impediments to tree planting included (a) the need to use trees without displacing agricultural enterprises and associated rural communities; (b) incomplete knowledge of the extent of tree planting necessary to restore water balances; (c) uncertainty about whether recharge or discharge area plantings were more effective; (d) an array of technical issues, associated with the move onto farmland (such as insect and weed control, establishment techniques, site selection and nutrition); and (e) obtaining investment to plant trees at the required scale.

Initially agroforestry was advocated with the expectation that the trees would reduce salinity and provide an income in their own right (Shea and Bartle 1988). Marketable commercial species capable of producing a return in a short rotation (10-12 yr) were sought; rotation length was crucial due to the high interest rates prevalent in the late 1980s. *E. globulus* had performed well in experimental plantings, was already planted over large areas on the Iberian Peninsula and was thus promoted as a profitable means of restoring the hydrologic balance (Shea and Hewett 1997). Based on overseas and local investment, *E. globulus* plantations on farmland have become a major industry in south-western Australia with about 153 000 ha established in the last 10 yr; this represents a dramatic acceleration of plantation establishment in Western Australia.

As available water is the principal determinant of *E. globulus* productivity, managing for maximum sustainable growth will also maximise the hydrologic impact of these plantations (Edwards and Harper 1996). There will always be a trade-off between productivity and risk in a climate where drought is an annual event. Faster growth will increase the risk of drought deaths and *E. globulus* must therefore be managed to ensure survival. The effect of drought on tree mortality is largely a function of total stored water, which can be estimated from soil volume. Strong relationships have been established between soil volume and drought deaths in *Pinus radiata* (McGrath *et al.* 1991) and *E. globulus* (Harper *et al.* 1998). Where soil water storage capacity is limited, tree deaths often occur during autumn, for example, deaths of *P. pinaster* occurred in the late 1940s and 1980s, of *P. radiata* in the 1960s, 1970s and 1980s and of *E. globulus* in the mid-1990s. Such events have prompted revision of site selection and silvicultural prescriptions.

There are strong climatic effects on growth, with a marked increase with increasing rainfall and decreasing evaporation. Estimated mean yields at 10 yr across the 600-800 mm yr^{-1} rainfall zone are 160 m^3 ha^{-1}, with low pan evaporation (<1500 mm yr^{-1}), and 130 m^3 ha^{-1} with high evaporation (>1500 mm yr^{-1}), whereas in higher rainfall (>800 mm) areas with low evaporation likely yields are around 250 m^3 ha^{-1} (Harper *et al.* 2000a). Other factors that affect the growth of *E. globulus* plantations include soil volume, soil fertility and stocking (Harper *et al.* 2000a). This analysis also suggests that both the location of trees in the landscape (slope position) and planting conformation (strips integrated with farming) will become more important in areas with decreasing rainfall and increasing evaporation. The sensitivity of *E. globulus* to salinity has also been demonstrated (Bennett and George 1995) and the species cannot be planted on discharge areas.

The rapid growth of *E. globulus* in the first rotation is at least partially attributable to water and nutrients accumulated under agriculture. The efficiency with which *E. globulus* has depleted the stored water built up under agriculture has been demonstrated by deep drilling beneath 8-yr-old *E. globulus* that showed water has been depleted to depths of up to 9 m (Crombie and Harper, unpublished; Smettem *et al.* 1999). The implications of this depletion of stored water are likely to be a greater risk of drought death and a depression of yield in the second rotation. The strong linkage of tree growth and survival to annual rainfall indicates the efficiency of trees in both depleting the stored water reserves in the profile and capturing all incoming rainfall; this demonstrates the key role trees can have in reducing recharge to groundwater.

Case Study 3: revegetation of farmland in the <600 mm rainfall zone

Revegetation of the <600 mm yr^{-1} rainfall zone of south-western Australia poses major challenges. Although this is the region where the most rapid and extensive deployment of trees is required to combat dryland salinity (State Salinity Council 2000), a range of technical and socio-economic issues has impeded adoption of trees. These include uncertainty about productivity and financial returns, poorly-developed markets for products, poor understanding about where to plant trees for best hydrological impact and perceived conflicts with agricultural activities. It is worth reflecting that similar concerns prevailed at the onset of the *E. globulus* industry.

The development of commercially-viable revegetation systems that provide hydrological benefits is necessary for widespread adoption by land-holders. Economic analysis of these systems should also account for off-farm benefits such as reduction of land degradation, rather than simply comparing the on-farm returns from trees with standard agricultural practice.

To this end CALM is involved in developing new tree-based industries in this region. It has entered partnerships to plant *P. pinaster* in the 400-600 mm yr^{-1} rainfall zone, both for timber and carbon sequestration (Shea 1998) and is developing mallee eucalypts (<600 mm yr^{-1}) for industrial oil, activated carbon, carbon sequestration and bioenergy (Bartle 1999). Cumulative areas planted to date are 11 800 ha and 9 000 ha, respectively.

While a number of options exist for the integration of trees into the agricultural areas of southern Australia, here we consider three of the most prospective options for broadscale revegetation (strategic placement of trees within catchments, integrated tree belts or alley farming, and phase farming with trees).

Strategic placement of trees

Where vegetation is seasonally water-limited, such as in the <600 mm rainfall zone, it will arrive at a leaf area index that is independent of species and in equilibrium with available water (Specht 1972; Hatton *et al.* 1998). Although complete revegetation will prevent further recharge, it is a costly solution. The challenge is to maximise the hydrologic impact of trees and generate the greatest return from tree planting.

There is some debate over the interaction between landscape positioning of trees and the proportion of catchments that need to be replanted with perennials to control recharge. The use of strategic plantations to intercept lateral flow appears limited to a few highly specific situations where trees can intercept relatively fresh groundwater (George 1990). Where trees can only prevent recharge, their lateral influence on water tables is quite limited. Indeed, after reviewing groundwater measurements at 80 sites, George *et al.* (1999) concluded that trees might need to occupy up to 80% of the landscape to prevent further drainage to groundwater. The view that trees have only a local effect on hydrology is consistent with measurement of groundwater levels under trees and adjacent farmland (e.g. Lefroy and Stirzaker 1999). The issue of the extent of lateral influence of trees, in the undulating terrain that comprises 60% of this region, has not been conclusively resolved for all areas of the wheatbelt (Bartle 1999).

Hatton and Dawes (2000) used the ecohydrological model WAVES and long-term rainfall records for Merredin (320 mm yr^{-1} rainfall), and predicted a strong influence of soil texture on recharge under crops. Predicted recharge ranged from 1 mm yr^{-1} for clayey profiles to 100 mm yr^{-1} for deep sandy profiles. This suggests that tree planting should target particular areas of farms for maximum recharge control.

Another debate has centred on the relative benefits of recharge compared with discharge plantings. Morris and Thomson (1983) demonstrated that trees planted in recharge areas were more effective in controlling salinity. The limited long-term impact of discharge plantings was demonstrated in multi-species eucalypt plantations on salt seeps after 15 yr (Greenwood *et al.* 1994). A tree plantation established on lower hill-slopes in and adjacent to a discharge area at Boundain showed initial decreases in watertable levels in the first five years, but increasing groundwater salinity under trees suggests future problems for their long-term survival (Stolte *et al.* 1997). Despite this increasing salinity these trees are now 20 yr old, and so the extent and time involved in root zone salinisation needs to be further investigated. It is important to understand the local hydrology prior to planting trees.

Although current practice suggests planting on recharge areas that often comprise the best agricultural land, the resultant trade-offs between using productive agricultural land for trees to save land down-slope has to be considered. Again, as demonstrated for *E. globulus*, direct returns from trees will offset the loss of land for cropping.

Trees planted on recharge areas must be integrated with agriculture. In south-western Australia, where cropping is the major economic activity, there are two principal options:

1. Permanent tree belts or ‘alleys’ (Lefroy and Stirzaker 1999), or
2. Trees in any planting design (blocks, strips) that are rotated across the landscape (Harper *et al.* 2000b).

Integrated tree belts or alley farming

Challenges with the placement of belts include determining whether they will intercept water either by lateral extension of roots, or through interception of down-slope flow. Developing this understanding will allow issues such as the spacing between belts to be optimized for different conditions, and help to resolve the number of tree belts necessary to account for the recharge under annual crops. This approach may also require the characterization of site attributes such as hydrology, and soil hydraulic gradient and conductivity. Alley width in any case will be constrained by a minimum width to allow the passage of machinery. In this region, where annual crops are sown as soon as possible following ‘opening’ autumn rains, using large machinery, there is an absolute minimum alley width of 40-60 m.

Water-use measurements on tagasaste (*Chamaecytisus proliferus*) integrated in 30 m rows with lupins and oats on profiles with 10 m of sand overlying clay indicate that soil water extraction was confined to 4 m either side of the tree rows (Lefroy and Stirzaker 1999). Calculations based on crop and tree water use, without any interaction between the root zones of the two, indicate that 24% of the catchment needed tree cover to prevent further water table rise, assuming all trees had access to the perched fresh watertable. This however was a species with a low leaf area index due to grazing. There are few field measurements of water use and productivity of alley farming systems, particularly in the valley floor soils, where subsoils are clayey and highly likely to be saline.

The lateral extension of tree roots from the belts increases water use, but this is at the expense of crop production. Management of integrated tree and crop systems requires a balance between productivity and water balance objectives. This will be difficult to achieve in the lower-rainfall areas where competition for soil water between trees and crops will be greatest. The development of tree species that provide a commercial return in their own right, such as mallee eucalypts, is necessary to offset direct and indirect reductions in crop or livestock production.

Phase farming with trees

An alternative approach is to rotate short-rotation tree crops with agriculture in ‘phase farming with trees’ (PFT), designed to grow trees at high planting densities in very short rotations (3-5 yr) (Harper *et al.* 2000b). These would rapidly deplete water in farmed catchments at risk of salinity, by utilising soil water while producing useable products such as wood fibre and biomass. The tree phase is followed by an agricultural phase of a length defined by the persistence of the hydrological buffer to recharge created by the trees drying out the soil profile to depth. Other potential benefits of this approach include improved soil structure and provision of a break in disease cycles and disruption in weed cycles. Production of large amounts of biomass suitable for electricity could decrease Australia’s emissions of Greenhouse gases.

The biophysical feasibility of the system has been modelled using WAVES (Hatton and Dawes 2000). This analysis suggests that the premise of the PFT system (*viz.* depletion of sub-soil moisture reserves under trees and subsequent recharge under agriculture) is realistic. In areas with deep, root-penetratable regolith, PFT may reduce overall recharge and provide storage for out-of-growing-season rainfall while allowing the continuation of farming. This analysis also suggests different tree-planting strategies are needed according to broad differences in soil and hydrological conditions. For example, although sites with deep soil profiles could be treated with PFT, other sites may be less suitable. Deep sandy soils and soils with an accessible fresh groundwater table may require permanent revegetation, whereas sites with low recharge rates may not need revegetation at all.

Conclusions

The capacity of tree plantings to slow or reverse salinisation of land and streams, by restoring the water balance to something approaching the situation prior to clearing, has been demonstrated for a number of catchments in southern WA. Two major challenges to broadscale planting of trees are the capacity to locate and arrange the tree planting to achieve the required hydrologic benefit, and to develop the economic drivers to facilitate the extensive replanting that appears necessary to achieve a reduction in salinity. An enormous investment in tree planting will be necessary to manage salinity over the Western Australian agricultural area of 18 M ha, 2.1 M ha of which are already salt affected. Revegetation of 20% of the landscape over a 10-yr period would require an annual planting program of 360 000 ha. Perspective is brought to the scale of this undertaking by considering that the annual rate of *E. globulus* planting is around 30 000 ha in an environment where economic returns are demonstrable. Thus any tree-based solutions to salinity will clearly require products that fit into mass rather than niche markets.

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