TREE PLACEMENT STRATEGIES FOR SALINITY CONTROL IN DRYLAND FARMING SYSTEMS OF SOUTHERN AUSTRALIA

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Abstract
Salinization threatens up to 17 Mha of Australian farmland, major fresh water resources and biodiversity. In Western Australia alone up to 450 species are threatened with salinity-induced extinction. The integration of woody perennials into farming systems is often advocated as a method of reducing recharge and remediating dryland salinity. Whereas complete revegetation is feasible in higher rainfall catchments where improved water quality is an outcome, such a planting strategy is impractical in lower rainfall areas due to the need to maintain cereal cropping. It is thus necessary to consider methods of integrating trees with agriculture that allow agricultural production whilst also improving the water balance. In low rainfall areas (<400 mm yr^{-1}) two options for incorporating trees have been proposed, alley farming between belts of trees and short phases of trees rotated with agriculture.

A survey of rooting depths of belts of farm forestry species (oil mallees (*Eucalyptus* spp.), *Eucalyptus astringens, Acacia acuminata* and *Allocasuarina huegeliana*) aged 4 to 11 years old found soil was dried to depths ranging from 4 to 10 m, with evidence of drying up to 15 m laterally. Phase farming with trees reduces recharge via the creation of a dry soil buffer to capture the leakage under subsequent annual crop rotations. In 2001, *Eucalyptus globulus, E. occidentalis, Acacia celastrifolia, Pinus radiata* and *Allocasuarina huegeliana* were planted at four densities 500, 1000, 2000 and 4000 stem ha^{-1}, as well as 500 stem ha^{-1} plus fertiliser. Species survival and growth were predominately affected by site characteristics and slope location as well as density in the second year of growth. Soil water content under high density Eucalyptus plantings was depleted to depths of 4 m after 2 years. The implications of these results for the use of deep-rooted perennials for recharge reduction and salinity control are discussed.

Additional Keywords: agroforestry, recharge, desertification

Introduction
Salinization on a massive scale threatens farmland, water supplies and remnant biodiversity across Australia, with up to 17 Mha potentially under threat (National Land and Water Resources Audit, 2001). In Western Australia alone up to 500 species are threatened with salinity-induced extinction (Keighery *et al.*, 2001). The problem is due to the alteration of the water balance in agricultural catchments, following the replacement of deep-rooted perennial plants with shallow rooted, annual plants, and consequent recharge to groundwaters (Allison *et al.* 1990; Tennant and Hall 2001). There is evidence that salinity has been a cyclical phenomenon in this landscape, with previous periods of salinization and recovery, albeit at millennial timescales (Harper and Gilkes, 2004). Although reforestation is often advocated as a means of restoring the hydrologic balance to pre-clearing conditions this option has not been widely adopted in low (<400 mm) rainfall environments (Harper *et al.*, 2001). This may be due to a lack of demonstrated commercial viability of trees in this rainfall zone and also a lack of conviction by landholders that trees will work. Also, it has been suggested that for many catchments the proportion of revegetation needed to restore water balances may be as high as 80% (George *et al.*, 1999) and trees may be required at close spacing, thus impeding the use of farm machinery. Revegetation may thus not proceed at the rate required.

Two main approaches appear promising for integrating trees with farming systems – belts of trees arranged across the landscape, with agriculture practiced between, and short phases (3-5 years) of trees rotated with agriculture. The premise of the former system is that the belts of trees will intercept surface and groundwaters before they salinize the valleys. Phase farming with trees (PFT) is a concept that assumes that trees will rapidly deplete soil moisture profiles to sufficient depth (>10 m) to provide a dry soil buffer for leakage from subsequent agricultural crops (Harper *et al.*, 2000; Robinson *et al.*, 2003). Crucial information requirements for both systems are the degree to which trees exploit sub-soils and the interactions between soil attributes and root systems. For alley farming to succeed in reducing recharge, roots will have to exploit adjacent cropped soils to several meters lateral extent. Similarly, phase farming with trees depends on the depletion of soil water to several meters depth. We have thus studied the vertical and lateral extent of trees roots, patterns of soil water uptake and the effect of different soil properties on rooting.

In this paper we summarize recent results from research we have undertaken to (a) evaluate the water depletion under belts of trees, (b) evaluate the phase farming with trees concept in the field and (c) establish a catchment scale evaluation of partial revegetation.

Materials and Methods

Survey of rooting depth and extent

Rooting depths and soil water extraction of a range of common farm forestry species including oil mallees (*Eucalyptus* spp.), *Eucalyptus astringens*, *Acacia acuminata* and *Allocasuarina huegeliana* were investigated at 10 sites representative of the major soils of the <600 mm rainfall zone of south-west Western Australia. Soil cores were taken to depths of up to 12 m directly underneath trees and in adjacent paddocks of annual crops or pasture. Cores with a diameter of 50 mm were sampled at 50 cm depth intervals, using a hollow auger wireline retrieval system. The soils of this region invariably comprise deeply weathered profiles formed on granitic or gneissic rocks, with sandy surface horizons of variable depth (0.1 to 5 m) overlying medium to heavy textured clays. It is within the latter layer that sodium chloride has accumulated, with this being remobilized by rising groundwaters.

Soil water matric potential (Greacen *et al.,* 1989) and gravimetric water content were determined from soil cores. Soil physical and chemical properties including, particle size analysis, total soil chloride content, pH and electrical conductivity (1:5), were determined at 50 cm depth intervals. Dry bulk densities were taken from backhoe pits and were estimated from sections of the soil core where possible. The depth of rooting was estimated by changes in soil water content and soil water matric potential with depth. The maximum extent of rooting was taken to be the depth where soil matric potential was similar to pre-dawn leaf potential measured with a pressure chamber at the time of soil sampling.

Phase farming with trees

The PFT trial site is located at Valema Farms (32.38^{o}S, 117.78^{o}E), near Corrigin, Western Australia, approximately 200 km east of Perth, the State capital. This site is typical of the sandy surfaced soils of the Western Australia wheatbelt. The climate is Mediterranean with a long-term annual average rainfall (90 years) and pan evaporation (12 years) of 375 and 1823 mm yr^{-1}, respectively. The trial design consists of three replicate blocks (Upper Slope, Mid Slope and Lower Slope) each with 25 treatments comprising five species; *Eucalyptus globulus*, *Eucalyptus occidentalis*, *Acacia celastrifolia*, *Allocasuarina huegeliana* and *Pinus radiata* planted at 500, 1000, 2000 and 4000 stems ha^{-1}, as well as 500 stems ha^{-1} plus fertiliser. The aim of this experiment is to determine how these manipulations of species, density and fertility treatments affect the rate and depth of water.

The three blocks are arrayed across different landscape positions in a single paddock that is normally used for wheat production. The Upper Slope block is on ferricrete gravel, the Mid Slope block in a concavity with a sandy duplex profile and the Lower Slope block on a sandy duplex profile with a moderately saline watertable at 2-3 m. Groundwater is >10 m deep in the Upper and Mid Slope blocks. Tree seedlings were planted in August 2001 onto land that had been cropped the previous year. Soil water contents up to 8 m depth have been measured at monthly intervals using a neutron moisture meter for each species planted at densities of 1000 and 4000 stem ha^{-1}, *E. globulus* for all densities and in a bare plot in each replicate. Tree height and diameter have been measured annually. Aboveground biomass (t ha^{-1}), and impacts on soil properties, and optimal methods of stump removal, will be determined at the completion of the experiment (2005).

Sub-catchment trial

These measurements are from plots of trees, and as salinity is a process that occurs at landscape-scales, in 2000 we established an experiment that comprised partial, but targeted, revegetation within an 80 ha catchment. This represents an evaluation of guidelines for the revegetation of farmland published in the Joint Venture Agroforestry Program publication "*Trees, Water and Salt*" (Stirzaker *et al.,* 2002). These guidelines have not been tested at catchment scales in the drier (<400 mm annual rainfall) environments that are representative of the wheat and wool-belt of much of southern Australia, thus a sub-catchment scale treatment was established on the Martin Family's property near Wickepin (32.74^{o}S, 117.69^{o}E), with 16 ha of planting in an 80 ha sub-catchment. This was planted and instrumented (climate station, weir, piezometers, neutron access tubes) in 2000. Eighty percent of the planting comprised a single commercial species (*Pinus pinaster) planted in two belts in upper and mid-slope positions* with lower slope, discharge areas comprised of a range of species (*Eucalyptus sargentii, E. loxophleba, E.*

globulus, E. occidentalis, Allocasuarina obesa, Pinus radiata, Acacia saligna) in replicated 625 m^2 plots. Groundwater levels are logged continuously, soil water measured with neutron moisture meter quarterly and tree growth annually.

Results and Discussion

Rooting depth survey

Soil water extraction profiles beneath trees were compared with soil bulk density, texture, pH and salinity. The rooting depths for existing plantings are shown in Table 1. Mallee eucalypt roots were found to penetrate and dry to wilting point massive clayey subsoils with bulk densities as high as 1.8-2.0 g cm^{-3} to depths of greater than 8-10 m within seven years of planting. Similarly, roots had penetrated subsoils with pH values ranging from 4.2 to 6.6 and electrical conductivity ($EC_{1:5}$) values up to 125 mS m^{-1}. At sites where the rooting depth was less than the maximum drilling depth, the limit to rooting was not correlated with any change in soil physical or chemical properties.

Our measurements suggest that there were no identifiable soil limits to tree root growth, despite extreme values of soil bulk density. In some instances hardpans within the soil prevented drilling, and it is uncertain whether the roots had penetrated these layers. The depletion of soil moisture beneath mallee eucalypts at seven years of age provides the best evidence that tree roots are able to occupy the soil profile in a relatively short amount of time. The mallee plantings investigated were mainly planted as belts rather than blocks, therefore deeper rooting may be expected when trees are planted at higher densities such as found by Eastham and Rose (1990).

In contrast to the majority of mallee plantings, the rooting depth of *E. astringens* was only 3.5 to 4m after four years. The plantation that we assessed was situated on a moderate slope, with a perched water table present in winter and this may also indicate the influence of site characteristics on the rate of soil water depletion. *Allocasuarina huegeliana* and *Eucalyptus loxophleba* had greater rooting depths than *Acacia acuminata* at the same site. Although comparisons over a greater number of sites and of more species need to be undertaken, these results suggest that some species may be more suitable for phase farming than others.

The width of root influence varied with soil type and site characteristics. At one site with an average annual rainfall of 400 mm and a clay loam soil, comparisons of pre-dawn leaf water potential and soil matric suction, soil water potential and soil water content profiles indicated that water was extracted by the mallees from at least 9 m from the edge of the belt and possibly out to 15 m. There appeared to be little or no effect of the trees on soil water at 20 or 25 m from the belt. This has implications for the optimum spacing and width of alley belts necessary to control recharge across these farming systems.

Phase farming with trees

Survival after the first year was strongly affected by slope position with no significant effect of planting density (Table 2). Although the replicates were situated in the same paddock, the gravelly upper slope block had much lower survival for all species compared with those in mid and lower slopes. Weed control, due to the occurrence of herbicide resistance weeds, was poor in the upper slope position. Tree height and leaf area measurements taken in August 2002 indicate that *E. globulus* and *E. occidentalis* had the greatest growth in the first year (Table 2). After two years, in addition to site, there were also effects of density and species on survival and growth. All densities of *E. globulus* and *A. celastrifolia* in the upper slope position and *E. globulus* planted at 4000 stem ha^{-1} in all slope positions had reduced survival after two years. The complete death in March 2004 of *E. occidentalis* planted at the highest density in the mid-slope block may be a result of a cemented soil layer at 4 m.

Neutron moisture meter count ratios are presented to indicate changes in soil water contents with time between tree and blank plots (Figure 1). Increasing count ratios correspond to increasing soil water contents. Consistent with the relatively high initial survival and growth, the largest changes in neutron moisture meter count ratio were measured beneath high-density plots of *E. occidentalis*. Within 20 months of planting, soil water content was depleted to a depth of 4 m beneath the high-density *E. occidentalis* plot in the Mid Slope plot (Figure 1A). In contrast, the soil water content beneath the high density *E. occidentalis* in the Lower Slope plot was depleted to 5 m at the end of summer only (Figure 1C). Neutron moisture meter count ratios measured beneath the blank plots were similar at all sampling times for all depths below 0.9 m (Figure 1 B, D).

Table 1. Site characteristics and rooting depth of various farm forestry species estimated from changes in soil matric potentials and soil water contents with depth as well as comparison with values measured in adjacent farmland at the end of summer.

Species	Age (yr)	Planting density (stem ha^{-1})	Soil texture	Depth of dry soil (m)	Maximum depth of drilling (m)
Eucalyptus astringens	4	1100	clay	4	7
E. astringens	4	2500	clay	3.5	6
Allocasuarina huegeliana	11	833	sandy clay loam	6.5	7.5
Acacia acuminata	11	833	clay	3	8
E. loxophleba subsp *loxophleba*	11	833	clay	6.5	12
Oil Mallee Eucalypts					
E. horistes	7	5000, 2-row hedge	sandy clay loam	10	10
E. kochii subsp *plenissima*	5	5000, 2-row hedge	sandy clay loam	9	11
E. kochii subsp *plenissima*	7	5000, 2-row hedge	clay loam	7.5	10
E. kochii subsp *plenissima*	9	2500	sandy loam	8.5	8.5

Table 2. Average survival (%) and height (m) of species in the replicate blocks in August 2002

	Planting Position					
	Upper slope		Mid slope		Lower slope	
Species	**Survival (%)**	**Height (m)**	**Survival (%)**	**Height (m)**	**Survival (%)**	**Height (m)**
A. celastrifolia	53 (19)	0.4 (0.1)	84 (17)	0.6 (0.1)	76 (17)	0.7 (0.1)
A. huegeliana	46 (19)	0.7 (0.1)	85 (27)	1.1 (0.3)	91 (13)	1.2 (0.3)
E. globulus	47 (11)	0.6 (0.1)	94 (6)	0.9 (0.2)	98 (2)	1.2 (0.2)
E. occidentalis	77 (3)	0.7 (0.1)	97 (2)	1.0 (0.1)	96 (3)	1.1 (0.1)
P. radiata	87 (19)	0.4 (0.1)	99 (2)	0.5 (0.1)	78 (22)	0.6 (0.2)

Measurements from the first two years of the trial indicate the potential of high density *Eucalyptus* plots to dry out the soil profile to 4 m in certain sites. Our previous modelling (Harper *et al.*, 2000) indicated that soil profiles need to be depleted to a depth of at least 10 m within 5 years for PFT to be viable, and it is quite feasible that this is achievable with the existing species and density matrix. Despite the variable growth and soil water use of species across the trial site the two Eucalypt species at the highest planting densities appear to hold most promise. The death of plots due to a cemented hard layer indicates that knowledge of the soil profile to depths of several metres is required for the PFT treatment to be successfully targeted. However, the implementation of PFT over large areas will decrease the significance of localised responses.

Sub-catchment experiment

Whereas the neutron moisture tubes (in March 2003) indicate the depletion of soil water to depths of 2-3 m, consistent with the Corrigin trial, no data are currently available from the peizometers or weir.

Conclusions

Trees, and particularly *Eucalyptus* species, appear to have the potential to deeply and rapidly penetrate subsoils across the region following revegetation. They will thus de-water soil profiles, reduce recharge to groundwater and lessen the risk of salinisation in agricultural landscapes. There are likely to be substantial differences in the efficacy of water extraction between tree species and this could form part of species selection criteria. The death of trees due to a cemented hard layer indicates that knowledge of the soil profile to depths of several metres is required for the phase farming with trees treatment to be successfully targeted. The rate and depth of water extraction of trees compared to systems using deep-rooted agricultural perennials (e.g. lucerne) requires resolution.

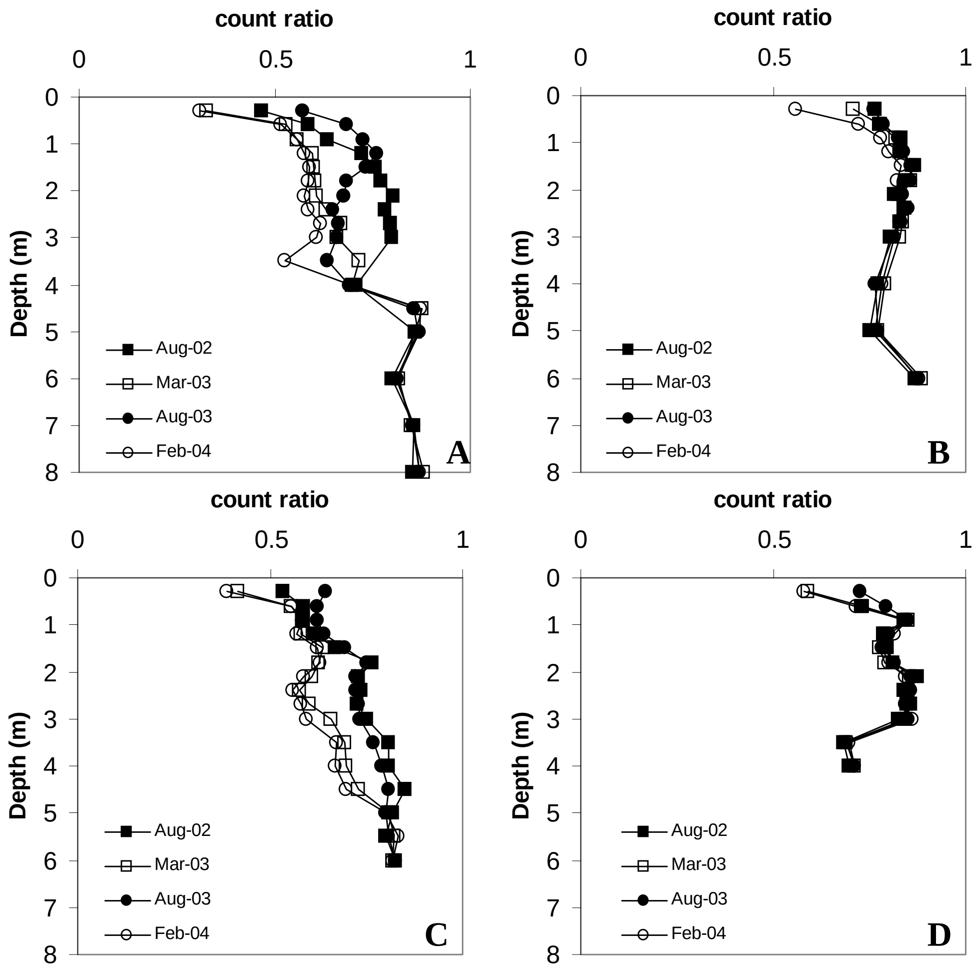

Figure 1. Neutron moisture meter count ratios, representing soil water profiles under *E. occidentalis* 4000 stem ha^{-1} (A, C) and blank plots (B, D) in the Mid Slope position (A, B), and the Lower Slope position (C, D).

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