Recharge reduction on degraded agricultural soils with agroforestry systems

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Abstract

Extensive clearing of native vegetation for agriculture has resulted in rising water tables and salinity in the lower rainfall areas (<600 mm y^{-1}) of Southern Australia. The re-introduction of deep-rooted perennials into farming systems is required to restore the water balance and remediate degraded agricultural soils. Alley farming (strips of trees and crop) and phase farming with trees have been proposed as options for reducing recharge while maintaining cereal cropping. For alley farming to succeed in reducing recharge, roots will have to laterally exploit adjacent cropped soils to several meters. Similarly, phase farming with trees depends on the depletion of soil water to several meters depth. To investigate the vertical and lateral extent of tree roots and patterns of soil water uptake, soil cores were taken to depths of up to 12 m, in transects perpendicular to 5-15 year old eucalypt belts at 5 sites across the 300-600 mm rainfall zone of south-western Australia. A range of soil properties, including matric suction, gravimetric water content, chloride concentration and bulk density were measured at 50 cm depth intervals. Lineal leaf area of belts and pre-dawn leaf water potentials were measured at the time of soil sampling. Results indicate that trees can exploit soil water to depths of at least 8-10 m within 7 years of planting. Results were similar in a range of other soils, with only silcrete pans and free water restricting root growth. This suggests that the premise of phase-farming with trees, which is the rapid depletion of soil water to depths of several meters to provide a buffer for water leaking from the subsequent crop phase is feasible. The lateral extent of the tree roots varied with site and soil type, however all were within 9-20 m. This has implications for the optimum spacing and width of alley belts necessary to control recharge across these farming systems.

Keywords: eucalyptus, rooting zone, soil water

Introduction

Replacement of native vegetation with agricultural systems has resulted in rising water tables and expanding areas of dryland salinity across southern Australia, current estimates predict over 17 Mha will be affected by 2050 (National Land and Water Resources Audit, 2001). This has significant implications not only for productive agricultural land, but also remnant native vegetation and rural infrastructure. In this Mediterranean climate, annual crops are shallow-rooted and only transpire for part of the year. As a consequence recharge under agricultural systems is one to two orders of magnitude greater than under native vegetation (Allison and Hughes, 1972; George *et al.,* 1997; Tennant and Hall, 2001). Watertable rise and the subsequent mobilisation of salt stored in the regolith occurs when drainage below the root zone into groundwater is greater than discharge. The re-introduction of deep-rooted perennials over large areas is recognised as the most effective biological strategy for reduction of the current hydrological imbalance. In the low rainfall areas (<600 mm y^{-1}), alley farming or integrating belts of perennial trees or shrubs with traditional crops has been proposed as one option for reducing recharge while maintaining areas for agriculture (Stirzaker *et al.,* 1999). An alternative option is to use a short-term rotation of trees (3-5 years) with crops. Modelling has indicated that densely planted trees have the potential to rapidly deplete soil water and provide a buffer for soil water storage during subsequent cropping years (Harper *et al.,* 2000).

Knowledge of the degree to which trees exploit sub-soils and the interactions between soil attributes and root systems is required to determine the potential effectiveness of alley and phase farming systems for recharge reduction. On sandy soils a range of eucalypt species dried out soil to 4 m within a few years (Eastham *et al.* , 1994) and similarly *Acacia saligna* and *Atriplex nummularia* belts depleted soil water to depths of at least 6m after 4 years (Knight *et al.,* 2000).

Studies of tree belt water use in low rainfall areas have been confined to sandy soils and cases where trees had access to relatively fresh groundwater (George, 1991; Knight *et al.,* 2000; Lefroy *et al.,* 2001; White *et al.,* 2001). Lateral extraction of water by tagasaste (*Chamaecytisus palmensis*) planted on deep sand was confined to 2-8m on either side of the tree belt (Lefroy and Stirzaker, 1999). This is unlikely to represent the maximum lateral extent as the trees had low leaf areas due to pruning and access to fresh perched water at 5.0-5.5 m, resulting in the investment of roots in the capillary fringe (Lefroy *et al.,* 2001). Where trees can access groundwater, large spacings between tree belts are possible (Stirzaker *et al.,* 1999), however large areas of the wheatbelt have duplex soils and saline watertables and the hydrological effect of belt plantings on these soils is unknown.

Since 1993, approximately 17 million oil mallee eucalypts have been planted in the wheatbelt of Western Australia (Parnell 2000; Wildy *et al.,* 2000) as part of the developing oil mallee industry. Potential products from these trees include pharmaceutical oil, solvent, bioenergy, activated carbon and carbon credits (Bartle *et al.,* 1999). Our aim was to investigate the hydrological zone of influence of mallee belts on a range of soils across a climate gradient. Soil matric potentials and soil water contents at the end of summer were used to estimate the vertical and lateral extent of the mallee belts. These soil water measurements were compared with estimates of the no recharge zone width using the relationship with leaf area developed by Ellis *et al.* (1999).

Materials and Methods

Study sites and soil sampling

Transects of soil cores were taken perpendicular to mallee belts at sites across south-west Western Australia between January and March 2001. Details of selected sites are summarised in Table 1.

Table 1 Site descriptions, vegetation characteristics and summary of estimations of zone of influence of mallee belts.

Location	Average Annual Rainfall (mm y^{-1})	Average Annual Evaporation (mm y^{-1})	Soil Type	Species	Vegetation Type and Width (m)	Vegetation height (m)	Vegetation Age (y)	Lineal Leaf Area (m^2 m^{-1})	Leaf Area Index (m^2 m^{-2})	Width of no recharge zone predicted from leaf areas (m)	Lateral extent of tree roots (m)	Width of zone of influence estimated from soil water measurements (m)
Wongan Hills (31.01°S, 116.83°E)	390	2308	Deep sand	E. kochii subsp. *plenissima*	Block edge 4	2	15	6.4	0.49	12.0	20	24
Narembeen (32.20°S, 118.20°E)	334	2169	Duplex sand clay	*E. polybractea*	Belt 5	5	6	9.4	0.45	21.0	12	29
Narrogin (32.99°S, 117.17°E)	507	1590	Deep clay loam	E. kochii *subsp.* plenissima	Belt 8	2-3	5	32.5	0.92	36.0	9	26
Wickepin (32.88°S, 117.57°E)	411	1826	Deep clay loam	E. horistes	Belt 5	2.5	7	15.8	0.65	25.0	9-15	23-35
Newdegate (33.10°S, 118.80°E)	356	1933	Deep loam	E. kochii *subsp.* plenissima	Belt 5	2	7	11.4	0.53	21.5	12	24-29

Soil cores with a diameter of 50 mm were sampled at 50 cm depth intervals using a hollow auger, wireline retrieval system at intervals of 1, 6, 9, 12, 15, 20 and 25 m from the base of the tree stem.

Matric suction of soil was determined using the filter paper method (Greacen *et al.*, 1987). Soil was gently packed into airtight containers with the filter paper immediately after sampling, then allowed to equilibrate for 6 days. The gravimetric water content was determined by oven drying a 30-50 g sub-sample for 24 h at 105°C. Dry bulk density of soil was estimated from intact sections of the soil core where possible.

Remaining samples were air dried and passed through a 2mm sieve. Particle size analysis was performed by the pipette method (Gee and Bauder, 1986). Electrical conductivity and pH (0.1 M CaCl) were determined on 1:5 soil: water suspensions (Rayment and Higginson, 1992). Total soil chloride was determined colormetrically (Taras *et al.,* 1975), and converted to the concentration in the soil water using the gravimetric water content. Osmotic suction of soil was estimated from chloride concentrations, assuming all salts were present as NaCl in the soil solution.

Plant biomass and leaf water potential

The lineal leaf area of tree belts was determined using the Adelaide method (Andrew *et al.,* 1979). Leaf area index was estimated by a regression with climate wetness (LAI=mean annual precipitation/mean annual pan evaporation)*2.89) (Ellis *et al.,* 1999). The width of the equivalent no recharge zone was estimated from the lineal leaf area and leaf area index as described by Ellis *et al.* (1999). A pressure chamber (Scholander *et al.,* 1965) was used to measure pre-dawn water potentials on a number of leaves from 2-3 trees on either side of the soil core transect.

Results and Discussion

Physical and chemical soil properties

A summary of the particle size analysis, electrical conductivity and pH for soil cores 1m from the tree belts are shown in Table 2. Soil salinity increases with depth at all sites with the exception of Wongan Hills. Bulk densities ranged from 1.7 to 2 g cm^{-3} in the sub-soils at Narrogin and Wickepin.

Soil and plant water potentials

Examples of the soil water potential profiles from Wickepin, 1, 9 and 25 m from the belt are shown in Figure 1. Low soil water potentials in the first 2 m of the soil profiles were correlated with high ferricrete gravel contents of 40 to 70% w/w. At 1 m from the belt, matric and total soil water potentials were lower than pre-dawn leaf water potentials at all depths to 10 m (Figure 1A), similar profiles were obtained 6m from the belt (data not shown). Trees may have accessed soil water 9 m from the tree belt as both matric and total water potentials from depths of 2 to 5.5 m were within the range of leaf water potentials (Figure 1B). Similar profiles were found 12 and 15 m from the tree belt. Water potentials of soil below 2 m at 20 and 25 m from the belt were higher than leaf water potentials (Figure 1C), suggesting that roots had not exploited this soil. The osmotic soil water potential was a minor component of soil water potential at all sites. The general relationship between the total water contents and soil water potentials indicates the usefulness of the latter technique as an indicator of the extent of rooting by plants.

Table 2 Physical and chemical characteristics with depth from soil cores sampled 1 m from tree belt.

Site	Depth	Particle Size (μM)				% gravel	BD	Ec (1:5)	pH
	(m)	<2	2-20	20-200	200-2000	w/w (>2 mm)	g cm^{-3}	MSm^{-1}	(0.01 M CaCl)
Wongan Hills	0.5-1.5	18	3	17	62	0	ND	2	5.2
	1.5-4.5	19	4	24	54	1	ND	3	5.7
	4.5-8.0	4	3	28	65	13	ND	3	5.8
Narembeen	0.5-1.5	21	5	34	41	3	ND	3	3.8
	1.5-3.5	18	6	34	42	22	ND	3	4.5
	3.5-4.5	18	7	32	43	13	ND	36	5.2
Narrogin	0.5-1.0	25	8	20	47	26	1.5	3	5.7
	1.0-2.0	25	11	18	45	26	1.6	10	5.6
	2.0-4.5	27	22	16	34	6	1.7-1.8	56	4.5
	4.5-8.5	32	15	18	35	5	1.7	105	4.4
	8.5-11.0	17	19	33	31	9	1.7	71	4.9
Wickepin	0.5-2.0	26	10	24	40	40	1.5-1.7	3	5.0
	2.0-3.5	36	20	20	24	10	1.8-2.0	7	5.3
	3.5-7.0	22	20	23	35	6	1.7-1.8	30	5.4
	7.0-10.0	22	22	24	32	10	1.7	89	5.4
Newdegate	0.5-1.0	28	11	16	45	11	ND	4	5.8
	1.0-2.5	15	15	17	53	5	ND	40	5.3
	2.5-3.5	11	20	21	48	9	ND	69	4.3
	3.5-6.0	15	23	21	42	2	ND	75	4.4
	6.0-8.5	17	25	23	34	4	ND	89	4.4
	8.5-10.0	21	25	18	36	4	ND	113	4.3

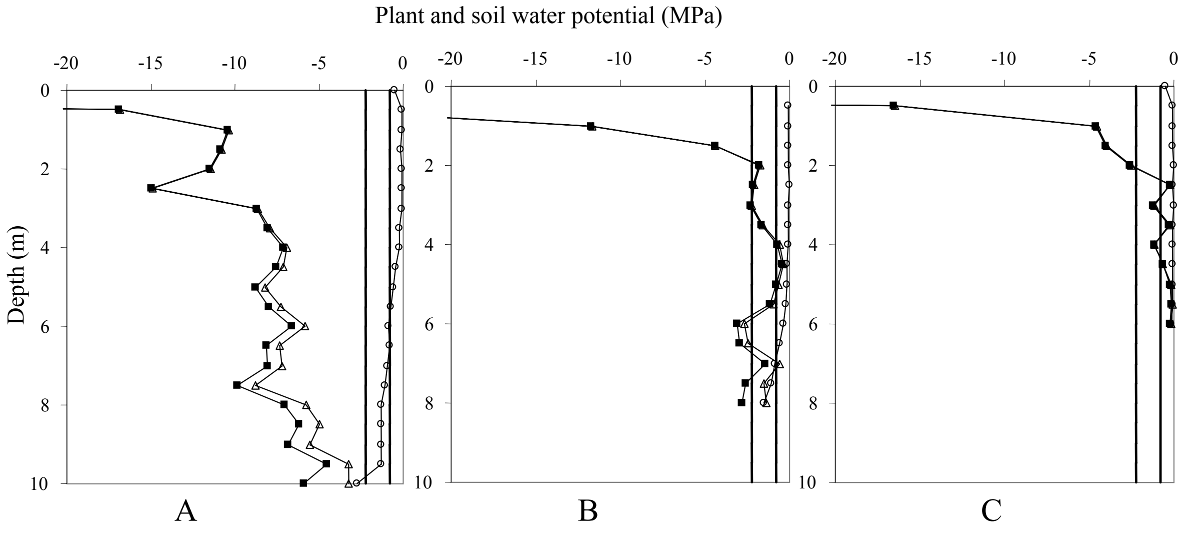

Figure 1 A-C Soil water potential (■), matric soil water potential (Δ) and osmotic soil water potential (○) profiles of core holes drilled 1 (A), 9 (B) and 25m (C) from the tree belt at the Wickepin site (January 2001). The range of pre-dawn leaf water potentials (0.8-2.2 MPa) at the time of soil sampling are indicated by the vertical bars.

Depth of tree roots

The depth of rooting was estimated using soil matric potential and water potential profiles. Soil profiles under tree belts were dried out beyond wilting point to the maximum extent of drilling (5-10 m) at all sites, with the exception of Narrogin where soil water potential was greater than leaf water potential at depths below 9 m (Figure 2). High dry bulk densities of up to 2 g cm^{-3} and low pH did not restrict rooting depths (Table 2).

Lateral extent of tree belt roots

Changes in soil water content and soil water potential (represented as absolute log values) with distance from the tree belt at the five sites are shown in Figure 2. Changes in soil water contents were consistent with soil water potentials. The lowest soil water contents and water potentials were found at Wongan Hills, the site with the oldest trees and sandy soils. At Newdegate the effect of an adjacent tree belt 40 m away is apparent in the soil water contents measured 20 m from the tree belt sampled. The lateral extent of the tree belt roots varied with site and ranged from 9 to 20 m (Table 1)

The hydrological zone of influence of tree belts presented for each site includes the width of the vegetation plus the distance to a significant increase in soil water content and soil water potential, with this distance being multiplied by 1 for a block edge and by 2 for a belt. At all sites the width of the zone of hydrological influence as indicated by soil water measurements was within 23 to 35 m (Table 1). The predicted width of the equivalent no recharge zone estimated from leaf areas ranged from 13 to 35 m (Table 1). The differences between the two estimates of the zone of influence at Wongan Hills and Narembeen may be due to the shallow depth of the soil profiles. At Narrogin, trees may still be using stored soil water as the trees are younger and the site has relatively high rainfall. The time for belts to reach the maximal extent of rooting is unknown, roots of 30 year old *Eucalyptus* have been found up to 20 m away (Stone and Kalisz, 1991). The mallee belts will be coppiced at 2-3 year intervals; the effects of this coppicing on rooting patterns will have to be resolved.

Conclusion

The roots of eucalypt mallee species have been found to rapidly penetrate and dry out sub-soils, to depths of 8-10 m within 7 years. This indicates the feasibility of phase farming to deplete unsaturated stores of water and prevent recharge in the subsequent crop rotation.

The hydrological influence of the tree belts ranged from 23 to 35 m, despite the large variation in soil type, profile depth and climate. Based on the current planting design mallee belts on land with little slope and no access to groundwater need to be spaced 20 to 30 m apart for 100% recharge reduction, assuming that the maximum lateral extent of rooting has been achieved. Sampling of a wider range of sites will enable determination of the change in the alley spacing with rainfall and soil type.

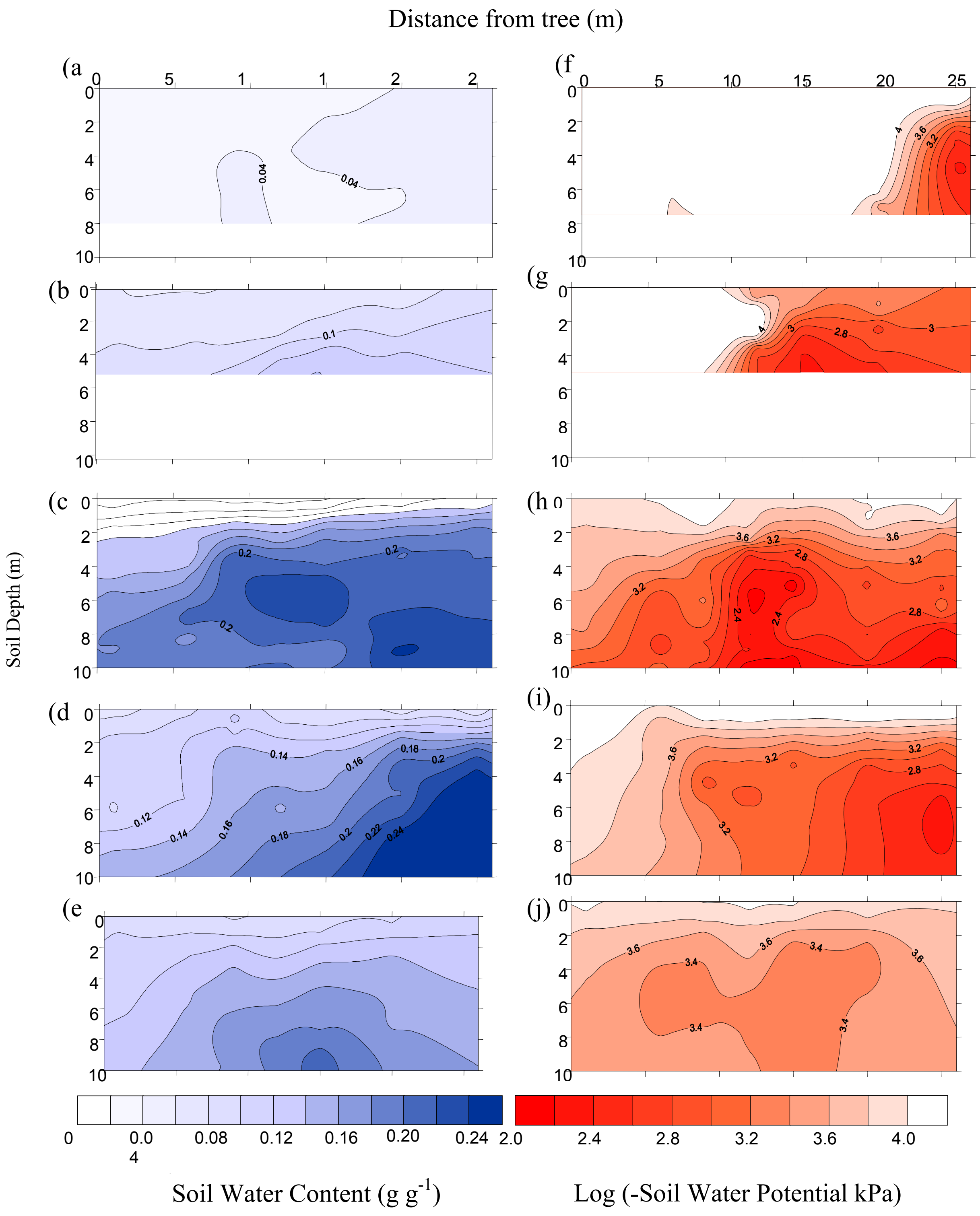

Figure 2 Soil water content (g g^{-1}) (a-e) and soil water potential (log (-kPa)) (f-j) of soil cores transects at Wongan Hills (a,f), Narembeen (b,g), Narrogin (c,h), Wickepin (d,i) and Newdegate (e,j).

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