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Soil water depletion by *Eucalyptus* spp. integrated into dryland agricultural systems

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Abstract Spatial patterns of soil water depletion by *Eucalyptus* spp. were surveyed to assess the potential of tree belts and short rotation phase farming with trees for groundwater recharge reduction and salinity control. Soils were sampled to depths of up to 10 m in transects perpendicular to 4- to 7-year-old mallee eucalypt belts (*Eucalyptus horistes, E. kochii* ssp. *plenissima, E. loxophleba* ssp. *lissophloia, E. polybractea*) and in a 4 year-old block of *E. astringens*. Results indicate that the eucalypt species can exploit soil water to depths of at least 8–10 m within 7 years of planting. The root systems of these eucalypts were able to penetrate clayey subsoils with bulk densities of up to 2.0 g cm^{-3}. Leaf area indexes of tree belts were 2–10 times greater than those predicted for natural vegetation, probably as a result of exploiting a greater amount of soil water stored under the agricultural system. The lateral influence of mallee belts, as indicated by soil water contents that were depleted to wilting point, ranged from 15–42 m. The resulting dry soil zone provided an effective barrier to groundwater recharge by incident rainfall thereby lessening the risk of salinisation in the agricultural landscape. The width of this barrier to recharge was predicted to range from 7 m to 54 m based on leaf area.

Keywords Salinity · Agroforestry · Water use · Root distribution · Groundwater · Mallee eucalypts

Introduction

The replacement of natural vegetation with agricultural systems has resulted in rising water-tables and expanding areas of dryland secondary salinity across southern Australia. Current estimates are that over 17 Mha will be affected by 2050 (National Land and Water Resources Audit 2001). This has significant implications not only for agricultural enterprises, but also for remnant natural vegetation and rural infrastructure, with up to 450 plant species likely to become extinct (Keighery et al. 2001).

Crops and pastures are shallow-rooted and have a transpiring leaf area for only part of the year. As a consequence, recharge under agricultural systems is one to two orders of magnitude

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greater than under natural vegetation (Allison et al. 1990; George et al. 1997; Tennant and Hall 2001). The low relief and groundwater discharge rates that occur over large areas of southern Australia have resulted in rising water-tables and mobilisation of salt stored within the unsaturated zone. Incorporation of deep-rooted perennial plants into catchments dominated by annual crops is commonly advocated as a strategy for managing dryland salinity, either as lucerne (*Medicago sativa*) or as various species of trees. In low rainfall areas (<600 mm year^{-1}), alley farming that integrates 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). Alternatively, "phase farming with trees" using ultra-short rotations (3–5 years) of tree crops has been proposed as an option to reduce recharge through the creation of a dry soil buffer for the leakage under subsequent annual crop rotations (Harper et al. 2000).

Knowledge of how trees exploit sub-soils and utilise soil water is required to determine the potential effectiveness of both alley and phase farming systems for recharge reduction. For example, biophysical modelling has indicated that phase farming with trees will be most suitable for recharge control on soils developed over deep unsaturated regolith materials (Harper et al. 2000) (e.g. >10 m deep) that are widespread across southern Australia (Churchward and Gunn 1983). While there are many observations of tree roots at depth (Canadell et al. 1996; Stone and Kalisz 1991), the physical and chemical constraints to tree root growth and rate of soil exploration by roots are not well defined. Previous studies have indicated that trees planted on sandy soils can extract water from depths of 8–12 m and prevent recharge laterally from 4 m within 4 years (Dye 1996; Eastham et al. 1994; Knight et al. 2002).

Our aim was to investigate the rooting depth and lateral zone of influence of eucalypts planted on land previously used for annual agriculture. Soil water content profiles at the end of summer were used to map the vertical and horizontal extent of the tree roots. Soil water measurements were compared to the equivalent no-recharge zones estimated using a relationship between lineal leaf area and recharge reduction (Ellis et al. 1999). Knowledge of the vertical and lateral extent of tree roots and soil water depletion is essential to assess the potential of phase farming with trees and alley farming systems for recharge reduction and salinity control.

Materials and methods

Study sites and soil sampling

Soil cores were taken from beneath tree belt or block plantings and in adjacent agricultural land at nine sites at six locations across south-west Western Australia between January and March, 2001 and 2002 (Fig. 1). Details of climate, vegetation characteristics and the type of planting (i.e. belt or block) are summarised in Table 1. The eucalypt mallee belts sampled consisted of 2 or 4 rows with 2 m between rows and 1 m spacing within rows. Canopy widths ranged from 5 m to 10 m. The canopy width for the block edge at Narembeen East included the tree rows that had an enhanced leaf area compared with the rest of the block. None of the tree belts had been harvested.

Soil cores, 50 cm in length with a diameter of 5 cm, were sampled to depths of 10 m where possible using a hollow auger. At several sites the depth of drilling was constrained by impenetrable material. At four of the sites soil cores were taken from transects orthogonal to the mallee eucalypt belts at intervals of 1, 6, 9, 12, 15, 20 and 25 m from the belt. At a fifth site at Newdegate, soil cores were only sampled out to 20 m, which was mid-way between two tree belts.

Soil analysis

The region has a Mediterranean climate, with an annual summer drought, thus the patterns of soil moisture content in late summer were considered to provide a proxy of root activity and distribution. The only significant rainfall (25 mm) in the 3 months preceding sampling in both years occurred on 3 December 2001, which

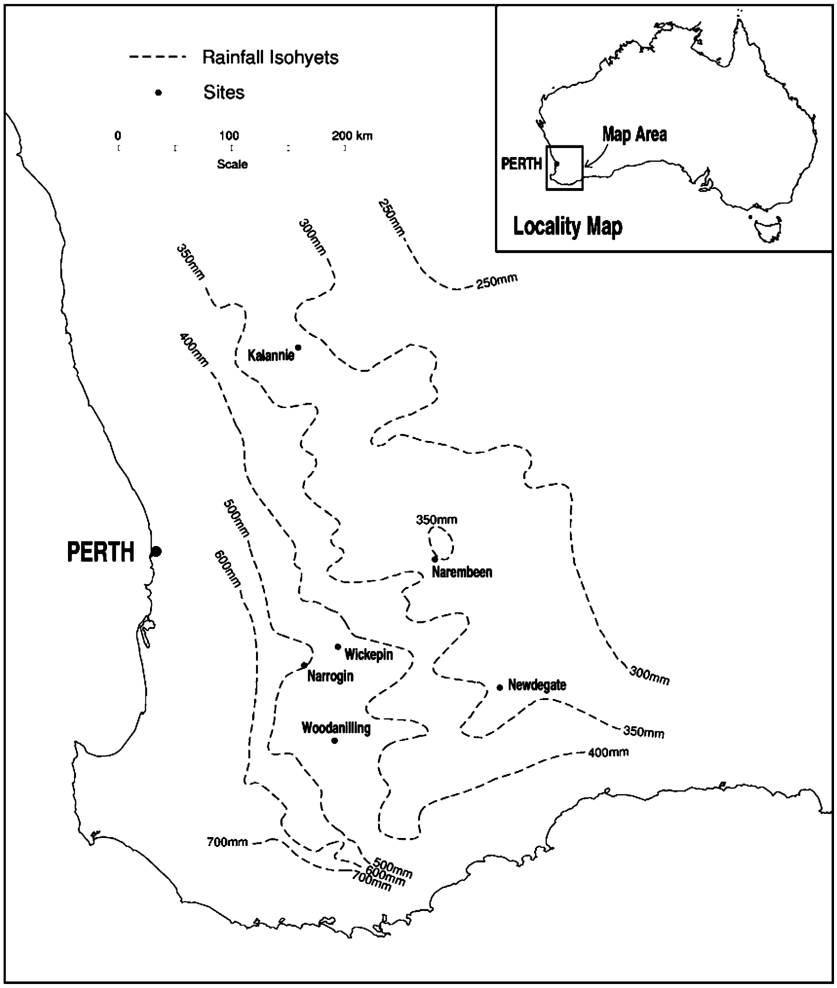

Fig. 1 Locations of study sites in south-west Western Australia

was considered unlikely to penetrate the deeper soil.

Gravimetric water content was determined by oven drying a 30–50 g sub-sample for 24 h at 105°C. Soil water matric potential was determined using the filter paper method (Greacen et al. 1989). Soil was gently packed around the filter paper and sealed in airtight containers immediately after sampling, then allowed to equilibrate for 6 days. The moisture content of the filter paper was determined by oven drying for 24 h at 105°C.

Particle-size analysis was performed by the pipette method (Gee and Bauder 1986). Soil pH was determined on 1:5 soil/0.01 M $CaCl_2$ and electrical conductivity (EC) was determined on 1:5 water extracts (Rayment and Higginson 1992). $EC_{1:5}$ values were converted to EC_e (George and Wren 1985). Total soil chloride was determined colorimetrically (Taras et al. 1975), and converted to the concentration in the soil water using the gravimetric water content. Osmotic potential of soil was estimated from chloride concentrations, assuming all salts were present as NaCl in the soil solution (Thorburn et al. 1993). Dry bulk densities were determined from cores taken from backhoe pits to depths of 1.5 m at Kalannie, Wickepin, Narrogin and Newdegate. Bulk densities at depth were estimated from sections of the soil core where unbroken fragments of at least 3 cm diameter were recovered.

Leaf area and leaf water potential

The lineal leaf areas (m^2 m^{-1}) of the tree belts were determined using the Adelaide method

Table 1 Site location, climate and vegetation characteristics

Site location	Rainfall (mm year^{-1})	Pan evaporation (mm year^{-1})	Vegetation characteristics				
			Species	Type	Age (year)	Height (m)	Width of belt (m)
1. Kalannie upper slope (30.18° S, 117.37° E)	311	2542	*E. polybractea*	2-Row belt	6	5	5
2. Kalannie middle slope (30.18° S, 117.37° E)	311	2542	*E. polybractea*	2-Row belt	6	5	6
3. Narembeen north (31.95° S, 118.52° E)	334	2169	*E. polybractea*	2-Row belt	6	5	5
4. Narembeen east (32.10° S, 118.55° E)	334	2169	*E. loxophleba* ssp. *Lissophloia*	Block edge	7	3	3
5. Narrogin south (32.99° S, 117.17° E)	507	1590	*E. kochii* ssp. *Plenissima*	4-Row belt	5	2–3	8
6. Narrogin north (32.99° S, 117.17° E)	507	1590	*E. astringens*	Block 2300 stem ha^{-1}	4	3	
7. Wickepin (32.88° S, 117.57° E)	411	1826	*E. horistes*	2-Row belt	7	2.5	5
8. Woodanilling (33.62° S, 117.22° E)	490	1608	*E. kochii* ssp. *plenissima*	Block	9	2.5	
9. Newdegate (33.10° S, 118.80° E)	356	1933	*E. kochii* ssp. *plenissima*	2-Row belt	7	2	5

(Andrew et al. 1979). A small branch was selected and removed from the tree belt to form the "leaf module". Two observers counted the number of leaf modules in a 6–10 m length of tree belt adjacent to the soil transect. All leaves were removed from the module and the leaf area determined using a planimeter. The total lineal leaf area (m^2 m^{-1}) was determined by the mean of the two estimates.

A pressure chamber (Scholander et al. 1965) was used to measure pre-dawn leaf water potential on several leaves from two to three trees on either side of the soil core transect. Measurement of pre-dawn leaf water potential was carried out within three days of the soil sampling. The leaf area index (LAI) of natural vegetation was predicted from site rainfall and pan evaporation shown in Eq. 1 (Ellis et al. 1999). Rainfall and pan evaporation data were obtained from the Bureau of Meteorology. Where measurements of pan evaporation were unavailable these were estimated by ANUCLIM (McMahon et al. 1996).

$$\mathrm{LAI} = 2.9 * \mathrm{rainfall}/\mathrm{pan\ evaporation} \qquad (1)$$

Results

Soil physical and chemical properties

In each case the soils were typical of those formed on deep weathering profiles of south-western Australia (McArthur 1991). Soils at Kalannie were uniform sands with varying depth to a silcrete hardpan. Sites at Narembeen had relatively shallow profiles, with gravelly sandy loam to a depth of 1 m overlying 3 m of sandy clay loam on granite bedrock. Sites at Wickepin, Woodanilling and Narrogin South, had soils comprised of a sandy surface dominated by ferricrete gravel to a depth of 25–60 cm, overlying an orange mottled clay (0.5–1 m), then orange–red clay and a white pallid zone. At Narrogin North, soils had a gravelly sandy surface to 50 cm overlying a clay layer at 2–4 m then sandy clay. Soils at the Newdegate site comprised a clay sand surface to 15 cm overlying a domed red mottled clay to 50–70 cm then white clay to several meters. The changes in soil particle size distribution and gravel content with depth for each site are shown in Table 2.

Bulk densities at Kalannie, Wickepin, Narrogin and Newdegate ranged from 1.5 g cm^{-3} to 2.0 g cm^{-3}. The overall soil pH (0.01 M $CaCl_2$) was acidic and at the majority of sites increased with increasing soil depth. The exceptions were soils at Narrogin, Woodanilling and Newdegate where soil pH was lowest between 4–8 m depth. Electrical conductivity of soil (EC$_e$) (mS m^{-1}) increased with depth at sites with duplex soils, including Wickepin, Narrogin and Newdegate (Table 2). EC*e* values at depths of 6–10 m were up to 1000 mS m^{-1}, which is classified as moderate to high salinity for these soil textures (Moore 1998).

Table 2 Soil physical and chemical properties of soil cores 1 m from the tree base for each site at 2 m intervals to the maximum extent of drilling

Site	Depth of drilling (m)	Depth of soil dried beyon wilting point (m)	Soil depth (m)	Particle size distribution (%)				Gravel (%)	Bulk density (g cm^{-3})	pH (0.01 M $CaCl_2$)	Ece (mS m^{-1})
				<2	2–20	20–200	200–2000				
Kalannie upper slope	8	8	0.5	16	4	14	66	0	1.7	3.6	55
			2.0	14	5	23	58	1	—	4.1	35
			4.0	4	4	28	64	6	—	5	20
			6.0	4	4	32	60	12	—	5.7	35
			8.0	7	2	31	60	43	—	5.6	62
Kalannie middle slope	2	2	0.5	13	3	20	64	6	1.5–1.7	3.8	499
			2.0	9	11	29	51	48	—	6.2	709
Narembeen north	5	5	0.5	31	2	26	41	1	—	3.8	38
			2.0	23	5	32	40	13	—	4.6	22
			4.0	20	3	39	38	18	—	5.3	435
Narembeen east	2	2	0.5	18	5	28	49	2	—	3.9	44
			2.0	25	6	26	43	4	—	4.7	96
Narrogin south	10	9	0.5	27	5	19	49	27	1.6	5.6	33
			2.0	20	17	16	46	27	1.6	5.6	116
			4.0	—	—	—	—	3	1.8	4.4	748
			6.0	40	8	9	43	8	1.7	4.4	806
			8.0	31	13	27	29	1	1.7	4.6	832
			9.0	24	16	31	30	5	1.7	4.9	933
			10.0	13	17	39	31	12	1.7	4.7	1144
Narrogin north	6	4	0.5	17	7	28	47	57	—	4.8	46
			2.0	54	7	8	31	12	—	5.2	81
			3.0	56	15	7	22	0	—	5.0	243
			4.0	22	22	12	44	3	—	4.7	586
			6.0	10	10	19	61	22	—	4.8	1277
Wickepin	10	10	0.5	34	4	18	44	56	1.7	4.8	21
			2.0	30	19	20	30	14	1.9	5.2	35
			4.0	22	20	23	35	14	1.8	5.4	151
			6.0	—	—	—	—	6	1.7	5.4	365
			8.0	27	24	17	32	33	1.7	5.3	908
			10.0	22	23	25	30	4	—	5.4	1122
Woodanilling	8	8	0.5	12	6	49	33	53	—	4.9	54
			2.0	44	8	25	23	13	—	5.9	32
			4.0	18	23	28	31	0	—	4.4	197
			6.0	28	17	17	38	4	—	4.6	309
			8.0	23	11	27	39	5	—	5.2	156
Newdegate	10	7.5–8.0	0.5	33	5	20	42	13	1.7–2.0	5.7	52
			2.0	29	12	12	47	4	—	5.4	341
			4.0	—	—	—	—	6	—	4.3	857
			6.0	27	26	15	32	0	—	4.5	878
			8.0	26	10	14	50	4	—	4.4	984
			10.0	35	9	11	45	8	—	4.4	874

Tree belt leaf areas

Leaf area indices of all tree belts were at least double and at some sites up to 10 times the values predicted for native vegetation (Fig. 2). The lack of a linear relationship between LAI and values predicted from climate parameters demonstrate the influences of site conditions, such as soil properties, on LAI of tree belts. This was particularly evident in the comparison of the two sites in close proximity along a slope sequence at Kalannie, where the LAI of upper and midslope sites were 1.5 and 3.1 $m^2 m^{-2}$, respectively, despite similar climatic conditions.

Rooting depth

Soil water contents and matric potentials measured underneath trees were compared with measurements taken from adjacent crop paddocks when soil properties and landscape positions were similar. Soil water potential was also compared to pre-dawn leaf potential. Examples of the soil water potential profiles 1, 9 and 25 m from the tree belt at Wickepin are shown in Fig. 3. Matric water potential was the major component of the soil water potential, although osmotic potential decreased with depth. At 1 m from the belt, matric and total soil water poten-

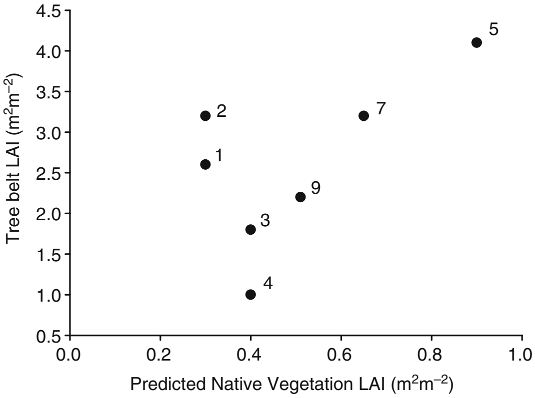

Fig. 2 The relationship between tree belt leaf area index and leaf area index of natural vegetation predicted from rainfall and evaporation of the sites across south-west Western Australia (LAI = 2.9*rainfall/pan evaporation). Numbers correspond to sites as shown in Table 1

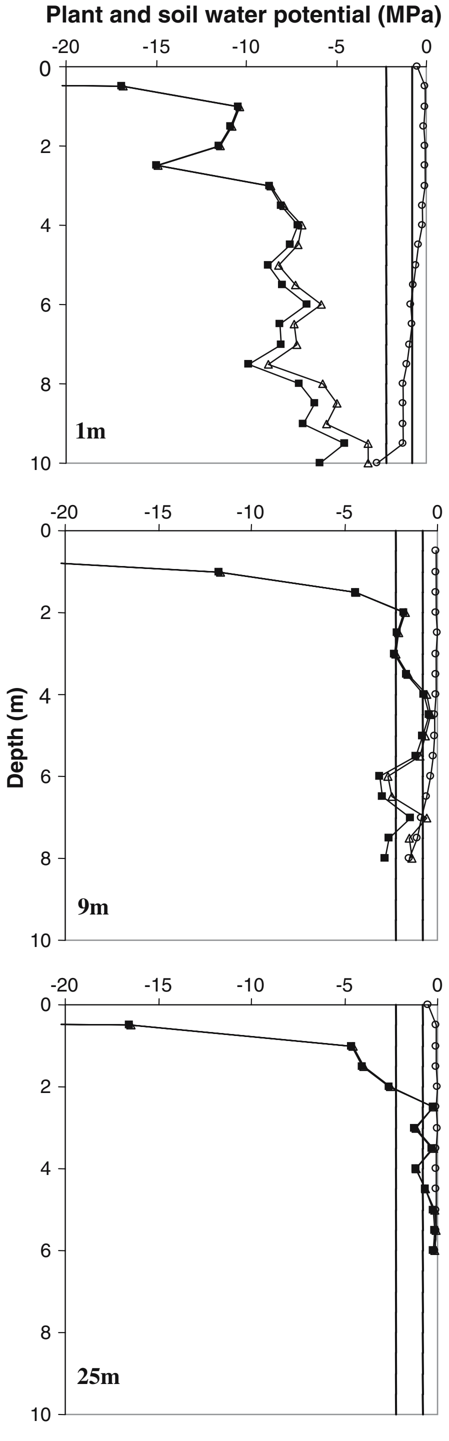

Fig. 3 Total soil water potential (■), matric soil water potential (Δ) and osmotic soil water potential (○) profiles of core holes drilled 1, 9 and 25 m from the tree belt at the Wickepin site (January 2001). The range of pre-dawn leaf water potentials (–0.8 to –2.2 MPa) of the adjacent trees at the time of soil sampling are indicated by the vertical bars

tials were lower than pre-dawn leaf water potential at all depths to 10 m, a similar profile was obtained 6 m from the belt. Trees may have accessed soil water 9 m from the tree belt as soil water potentials in this position at depths of 2–5.5 m were within the range of leaf water potential. Similar profiles were found at 12 and 15 m from the tree belt. Soil water potential below a depth of 2, 20 and 25 m from the belt was higher than leaf water potential, suggesting trees had not accessed water at these distances.

At several sites hard layers that could not be penetrated by drilling were encountered, and the full depth of drilling was not possible (Table 2). It was considered that this may have been due to the presence of siliceous pans within the regolith. It is not certain whether these materials occur as continuous sheets, that are impenetrable to roots, or are discontinuous.

Rooting depths estimated from soil water potential and soil water contents for each the site are shown in Table 3. Rooting depths of mallee eucalypt at the majority of sites were at least to the maximum extent of drilling. The two exceptions were *E. kochii* spp. *plenissima* at Narrogin South and Newdegate, where rooting depths were estimated to be 9 and 7.5–8 m, respectively. Soil water potentials beneath the *E. astringens* at Narrogin North were lower than the leaf water potential to 4 m depth, suggesting that the trees were not accessing water below this depth.

Zone of hydrological influence of tree belts

The changes in soil water content with depth and lateral distance from the tree belts were summarised by kriging the data for each hole using a linear semi-variogram model and the package Surfer 7.0 (Scientific Software Group 2003). Examples for four sites; Narambeen, Narrogin South, Wickepin and Newdegate, with relatively deep profiles are shown in Fig. 4A–D. Soil water contents and water potentials in each case increased with depth and distance from the trees. Where there was a hardpan at Narembeen North, the lateral moisture depletion appears to be more pronounced.

Soil water potential data are presented as absolute log values (Fig. 4E–H). Increases in soil water potentials with increasing soil depth and distance from the tree belt were consistent with changes in soil water content (Fig. 4A–D). Log water potentials of 3.2–3.4 correspond to soil water potentials of –1.5 to –2.5 MPa, with –1.5 MPa generally taken as an approximation of permanent wilting point (Reeve and Carter 1991). Pre-dawn leaf water potentials for trees at Narembeen North, Narrogin South, Wickepin and Newdegate were –2.3, –1.1, –1.3 and –1.3 MPa, respectively. The soil depth and distance from the tree belt where soil water potential corresponds to leaf water potential give an approximation of the zone of rooting. At Newdegate the soil water potentials were lower than leaf water potential at all depths and distances from the tree belt. In general, the lateral extent of rooting increased with decreasing rainfall and shallower soil profiles (Tables 1, 3).

The zone of hydrological influence presented for each tree belt includes the width of the vegetation (stem to stem) plus the distance to where a significant increase in soil water and soil water potential occurs, multiplied by one for a block edge and by two for a belt. The width of the zone of hydrological influence for tree belts at the six sites ranged from 14 m to 42 m (Table 3). The predicted equivalent no-recharge zone, defined by Ellis et al. (1999) as the ratio of tree belt lineal leaf area to natural vegetation LAI values, for the same sites ranged from 7 m to 54 m (Table 3).

Discussion

Vertical extent of tree roots

Roots of mallee eucalypts were found to remove moisture from soils to depths of at least 8–10 m after only 7 years of growth. This result is also broadly consistent with those from a study of soil moisture profiles of natural mallee vegetation that found roots influenced the gain and loss of soil water to depths of at least 5 m and root material was found at depths of 28 m (Nulsen et al. 1986).

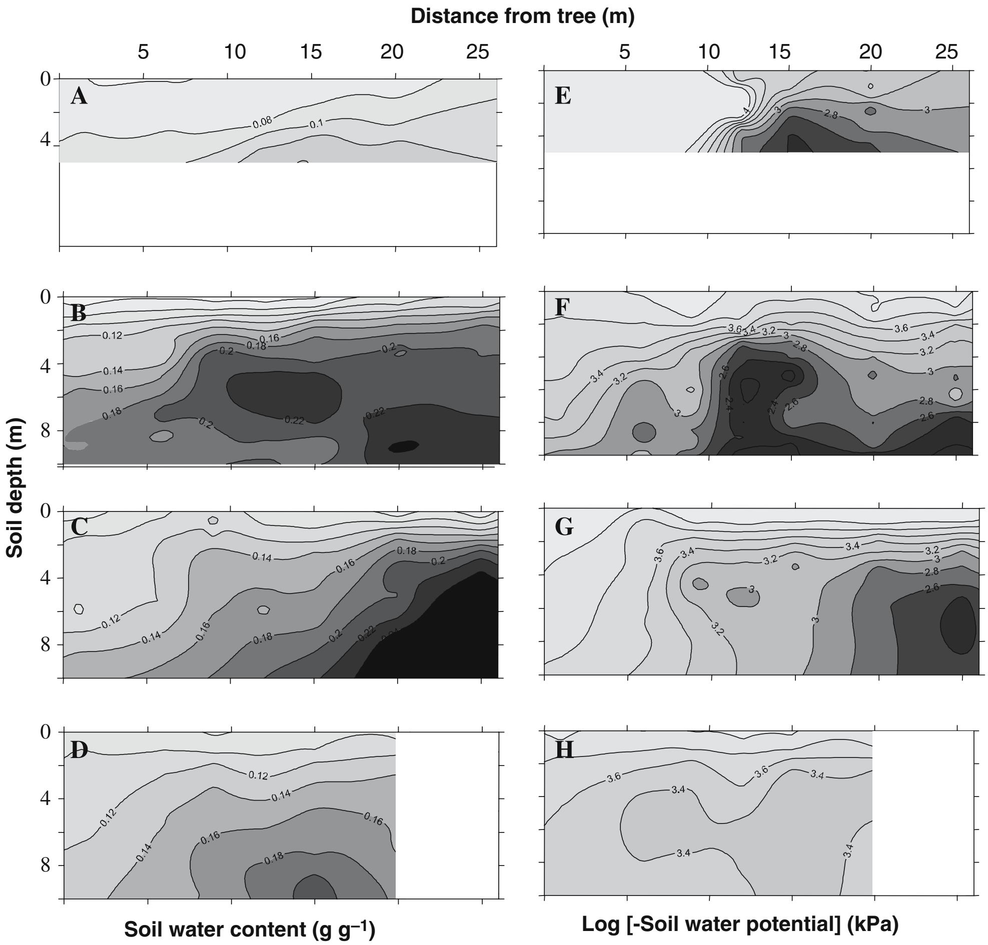

Fig. 4 Soil water content (g g^{-1}) (**A**–**D**) and soil water potential (log (–kPa)) (**E**–**H**) of transects drilled to depths of up to 10 m perpendicular to tree belts at Narembeen North (**A**, **E**), Narrogin South (**B**, **F**), Wickepin (**C**, **G**) and Newdegate (**D**, **H**)

Deep rooting occurred across a range of soil textures from sand to clay and with soil bulk densities of up to 2.0 g cm^{-3}. High bulk density and soil strength have been shown to restrict root and tree growth and reduce soil water extraction (Nambiar and Sands 1992). At sites where maximum rooting depths did not reach the maximum extent of drilling, there were no indications that soil properties were restricting vertical root growth. The rapid exploration of the subsoil by mallee roots may be facilitated by pre-existing root channels of the previous natural vegetation. The extent to which these channels promote rapid recharge and preferential water flow warrants further investigation in order to fully determine the significance of de-watering of the unsaturated soil profile.

The results have important implications for soil water extraction for recharge control, with mallee belts integrated into agricultural systems having the potential for extracting soil water at depth within seven years of planting. Similarly, the premise of phase farming with trees, viz. the rapid depletion of soil moisture to depth appears to hold true.

In this study where it was possible to examine soil profiles to a depth of 10 m (Narrogin South, Wickepin and Newdegate), those profiles immediately adjacent to the trees had soil moisture deficits of 680–1870 mm compared to those pro-

Table 3 Zone of hydrological influence for mallee eucalypt belts estimated by leaf area and changes in soil water content

Site	Lateral extent of tree roots (m)[a]	Width of zone of influence (m)[b]	Tree belt leaf area index (m^2 m^{-2})	Width of equivalent no recharge zone (ENOR) (m)[c]
Kalannie middle	15–20	32–42	3.1	54
Narembeen North	12	26	1.9	21
Narembeen East	13	15	1.1	7
Narrogin South	9	24	4.1	36
Wickepin	9–15	20–32	3.2	25
Newdegate	6	14	2.3	21

For site details, see Table 1

[a] Estimated from changes in soil water contents with distance from tree belt

[b] Vegetation width (stem to stem) plus lateral extent of tree roots multiplied by 1 and 2 for block edge and belts, respectively

[c] Predicted from lineal leaf area measurements

ENOR B = LLA tree belt/predicted LAI natural vegetation

files at 20 or 25 m distance under crop or pasture. This was calculated assuming a bulk density of 1.8 g g^{-1}.and ignoring the surface 2 m as this zone can be affected by the roots of annual agricultural plants. This is consistent with the results of Knight et al. (2002) who found a 600 mm deficit under 4 year old *Atriplex nummularia–Acacia saligna* belts. This drying of the soil profile under perennial mallee stands can be contrasted with the 50–150 mm deficit commonly found for lucerne (Ward and Asseng 2002), the farming system advocated for salinity control in southern Australia.

Hydrological zone of influence of tree belts

The high leaf area indexes of tree belts compared to predicted values for natural vegetation indicate that all of the mallee belts had access to water in addition to that received through rainfall on the planted area. Water-tables were not present and there was minimal run-on at all sites with the exception the midslope site at Kalannie. Potential sources of additional water include stored soil water in the unsaturated zone at depth and lateral exploration of roots beneath the root zones of the adjacent crop or pasture. Trees planted on agricultural land have access to the store of water that has accumulated below the shallow root-zone of annual plants. High rates of growth and high leaf areas will be maintained until the stored water has been depleted. For trees planted in belts the depletion of stored soil water may be compensated by further lateral expansion of roots. The lateral hydrological influence of the tree belts, including both sides of the belts, ranged from 14 m to 42 m, at sites differing in climate, soil properties and profile depth, and for tree belts of differing age and width. Widths of the no-recharge zones predicted from leaf areas encompassed a wider range, 7–54 m. The difference between the width of the zone of influence of tree belts estimated by soil water characteristics and leaf area was up to 12 m. The under estimation of the zone of influence by leaf area measurements at Wongan Hills and Narembeen may be due to the relatively shallow soil profiles. Therefore some caution is required when using only leaf area to predict zones of no recharge for tree belts without any information on the underlying regolith. However, this study confirms the usefulness of lineal leaf area as a rapid, inexpensive predictor of the zone of recharge reduction provided by a tree belt.

The time required for tree belts to reach the maximal extent of rooting is unknown. Roots of 30-year-old *Eucalyptus* spp. have been found to extend 20 m (Stone and Kalisz 1991). Remnant blocks and belts of mature mallee vegetation can reduce soil water recharge up to a distance of 10–32 m from the trees, depending on the site (Ellis et al. 1999). This is in contrast to a salmon gum (*E. salmonphloia*) plantation where recharge was reduced up to 60 m away from the plantation. Given the values measured for natural mallee vegetation it is likely that the lateral extent of the mallee belts will increase further with time. Further increases in the lateral extent of rooting below 2 m will result in reduced recharge without increasing tree-crop competition. The potential of tree roots to access this region of the soil is indicated by changes in soil water below a depth of 2 m at distances greater than 6 m from the tree belts. However, competition between tree and crop roots in the upper 2 m of soil remains a difficult issue in low rainfall areas (Stirzaker et al. 2002).

Implications for revegetation of semi-arid south-western Australia

Mallee belts consisting of two- to four-tree rows planted on land with little slope and no access to groundwater need to be spaced less than 20–30 m apart for 100% potential recharge reduction. This calculation is based on the lateral extent of rooting after 7 years and the calculated spacing could potentially increase with tree age if roots extend further. It also assumes that the water that falls on the bays between the belts does not bypass the belts by either overland flow or by entering the deeper regolith and flowing beneath the root zone.

Mallee belts will be harvested at 2- to 3-year intervals and the effects of regular harvesting on root growth and soil water content need to be investigated. Lucerne, a perennial pasture, has also been proposed as an option for salinity control as it has deeper roots and allows less drainage beyond the root zone in comparison to annual crops and pastures (Ward et al. 2002). In suitable areas, incorporating lucerne or other perennial pastures into crop rotations between the tree belts may enable alley width to be increased while maintaining recharge control. Alternatively, the rooting depths of mallee eucalypts after 7 years growth indicate that phase-farming with trees may have potential to be developed for areas with duplex soils and no lateral flow.

Conclusions

Establishing mallee eucalypt stands and belts appears to result in the deep and rapid penetration of subsoils across the region studied, resulting in the de-watering of soil profiles, both vertically, to depths of 10 m, and laterally to distances of 6–20 m from belts. The tree roots have penetrated sub-soil materials with properties that would normally be considered to constrain root growth. The resultant zone of no recharge is substantially greater than the width of the tree belt, thus conferring a greater hydrologic advantage in terms of recharge control. The resulting dry soil zone provides an effective barrier to groundwater recharge by incident rainfall thereby lessening the risk of salinisation in agricultural landscapes.

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