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The ability of *Distichlis spicata* to grow sustainably within a saline discharge zone while improving the soil chemical and physical properties

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Abstract. Landholder observations indicate that the growth of *Distichlis spicata* in saline discharge sites improves the soil condition. An extensive soil sampling survey was conducted at the Wickepin field site in Western Australia, where *D. spicata* had been growing for 8 years, to test the hypothesis that this halophytic grass will make improvements in chemical and physical properties of the soil. Soil measurements included saturated hydraulic conductivity, water-stable aggregates, root length and dry weight, electrical conductivity, pH, and soil nitrogen and carbon. Results confirm that marked differences in soil properties occurred under *D. spicata*. For example, a 12-fold increase in saturated hydraulic conductivity occurred where *D. spicata* had been growing for 8 years, compared to adjacent control soil where no grass had been growing. There were also improvements in aggregate stability, with the most notable improvements in the top 0.10 m of soil, again with the greatest improvements occurring where 8 years of growth had occurred. Soil nitrogen and carbon increased under the sward, with the biggest increases occurring in the top 0.10 m of soil. Electrical conductivity measurements were more variable, mostly due to the large spatial and temporal variation encountered. However, the findings generally support the proposition that the growth of *D. spicata* does not lead to an accumulation of salt within the rooting zone.

Additional keywords: reclamation, halophyte, salt grass, NyPa forage, salt tolerance, saltland pasture.

Introduction

Soil salinity is a major issue within many Australian farming systems throughout southern Australia. The area affected by or at risk to salinity, due to shallow or rising water tables, was estimated at 5.7 million hectares in 2000, with the potential to reach 17 million hectares by 2050 (Audit 2001). These sites are generally regarded as degraded from a chemical and physical perspective, with high concentrations of dissolved salts within the root-zone, and are commonly waterlogged. There are very few ways that landholders can use these degraded areas for commercial use. In most cases, they are abandoned and lost from the farming system.

Distichlis spicata var. yensen-4a is a halophytic pasture grass that has been selected for forage production on saline land (Yensen and Bedell 1993; Yensen *et al.* 1995). The grass was introduced into southern Australia in 1994 and trialed to determine its suitability for forage production on saline farmland (Leake *et al.* 2002). During this time, research has been focused on establishment techniques and forage potential (Sargeant 2003; Sargeant *et al.* 2006). Since its introduction, *D. spicata* has been established successfully in a seasonally waterlogged saline discharge site where it has been able to grow and continually spread.

One of the major benefits of growing *D. spicata* on saline discharge sites is its ability to produce green forage throughout the summer months when it grows actively. In the past, the feed value of *D. spicata* has been questioned. However, unreplicated feed tests conducted by farmers have shown that this halophytic pasture species can produce forage that is suitable as a maintenance diet for ruminants throughout the summer period, with ash concentrations ranging from 10 to 12%, metabolisable energy values up to 9.5 MJ ME/kg DM, and crude protein up to 17%, when the sward has been well managed. This feed is produced throughout the warmer months of the year, through a period when there is very little standing green feed available, and supplementary feeding of stock to maintain liveweights is common.

Several landholders have observed that the condition of the saline soils has improved where *D. spicata* had been grown for several years. The soils appeared to ‘hold together’ better, and in some cases the area has been re-colonised by less salt tolerant species (R. Matthews, pers. comm.). A rhizocanicular effect had also been hypothesised, whereby decaying roots and rhizomes would leave a network of channels throughout the soil profile which would increase water percolation (Yensen 1997).

This paper reports on a field survey that was set up to test the hypothesis that the growth of *D. spicata* improves the chemical and physical properties of the salinised soil in which it grows. An extensive field survey was carried out at a discharge site where a sward of *D. spicata* had been growing for up to 8 years. Two other discharge sites located on the property were also sampled where *D. spicata* had been growing for 5 years. Soil

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properties were compared between different aged swards to test this hypothesis.

Materials and methods

Site description

Soil sampling was conducted at 3 saline discharge sites on a property at Wickepin in Western Australia. These sites were established with *Distichlis spicata* var. yensen-4a at 5–8 years before the initial sampling period. There were adjacent areas where no *D. spicata* was planted which were used as controls. All of these sites were established by vegetative means.

Rainfall

The average annual rainfall at Wickepin is 411 mm and this predominantly falls throughout the winter months (Table 1 and Fig. 1). Since 1997, when the mother plot area was established (see below), the annual rainfall at Wickepin has generally been less than the long-term average, with only 3 of the 10 years with rainfall exceeding the average (Table 1). The farm is located ~25 km east of Wickepin, and so, the actual rainfall at the survey site is less than that at Wickepin. Figure 1 shows that before the first sampling period in 2005, monthly rainfall exceeded the average. In 2006, monthly totals were below average in the months leading up to the sampling period.

Mother plot

The mother plot site (32°42′15″S, 117°44′30″E) was established with *D. spicata* in 1997. This site is located on the upper edge of a saline discharge site, which is halfway down a gentle slope, with a cropped paddock above the plot. A surface drain is located upslope from the site that runs along the contour of the land. The control area, where no *D. spicata* plants were established, occurred downslope of the established area. The control area was approximately 0.20 m lower than the 8-year-old treatment, which was 10 m upslope, and had a patchy covering (~50%) of immature sea barley grass (*Hordeum marinum*). The

Table 1. Seasonal and total yearly rainfall data (mm) for Wickepin since the *D. spicata* sward was established

Summer rainfall for each year, includes the December rainfall of the previous year, whereas yearly rainfall is for the calendar year. Data supplied by the Australian Bureau of Meteorology

Year	Summer rainfall	Autumn rainfall	Winter rainfall	Spring rainfall	Total yearly rainfall
1997	44	108	137	61	346
1998	0	102	205	74	395
1999	22	121	204	91	440
2000	128	41	187	24	364
2001	2	42	181	65	319
2002	46	54	120	76	277
2003	58	148	202	78	478
2004	17	48	174	82	321
2005	7	205	149	75	439
2006	140	66	125	47	375
Long-term average 1912–2006	39	99	197	76	411

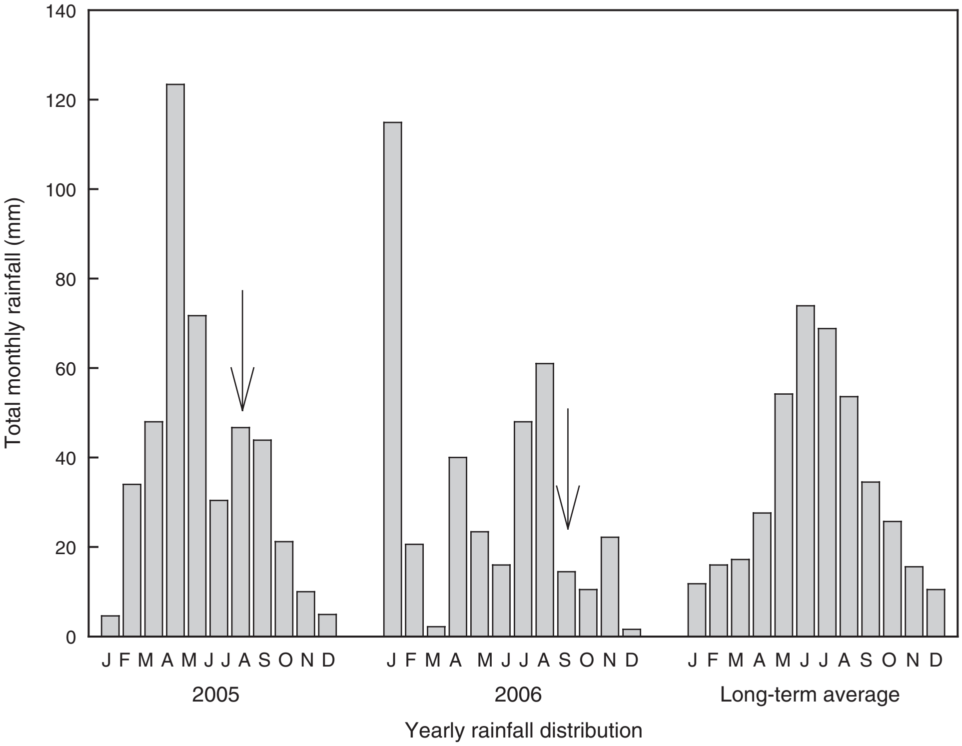

Fig. 1. Monthly rainfall distribution throughout 2005 and 2006, along with the long-term average (1912–2006), at Wickepin. Arrows indicate when the 2 sampling periods occurred. Data were supplied by the Australian Bureau of Meteorology.

soil texture at this site was sand in the top 0.10 m, sandy loam in the 0.10–0.20 m layer, and sandy clay loam in the 0.20–0.30, and 0.30–0.50 m layers. Soil $pH_{(water)}$ ranged from 6.6 to 6.8 in the topsoil, and increased with depth to 6.8–7.0 at 0.30–0.50 m depth.

Sand plain

The sand plain site (32°42′50″S, 117°44′54″E) was established with *D. spicata* in 2000. The area was planted as a transect down the slope, with the adjacent area that was not planted also located down the transect. This control area also had patches of sea barley grass that covered approximately 50% of the soil surface. The soil $pH_{(water)}$ ranged from 5.5 to 6.3 in the topsoil and 5.6 to 6.1 at 0.20–0.30 m depth. The soil had a sand texture at 0–0.30 m.

Flats

The flats site (32°40′60″S, 117°45′0″E) was also established with *D. spicata* in 2000. This site was planted in a square block in a discharge site. The adjacent control was located 10 m upslope from the established area and was covered with patchy sea barley grass that covered approximately 50% of the soil surface. The soil texture at the 3 sampling depths (0–0.10, 0.10–0.20, and 0.20–0.30 m) was a sandy loam. Soil $pH_{(water)}$ ranged from 6.3 to 6.8 in the topsoil, and increased with depth and ranged between 6.6 and 7.4 at 0.20–0.30 m depth.

Sampling procedure

Destructive soil samples were collected from all sites in July 2005 and again from the mother plot in September 2006. The mother plot was sampled more extensively, with destructive samples taken in 2005 and 2006 from 0–0.10, 0.10–0.20, 0.20–0.30, 0.30–0.50, and 0.50–0.70 m using a 50-mm-diameter sampling tube, with intact cores taken in 2005 from 0–0.06, 0.10–0.16, and 0.20–0.26 m depths. Obtaining samples from the 0.50–0.70 m depth proved to be quite problematic, and hence only samples from the 8-year-old treatment were collected. All sampling profiles were replicated 6 times. Soil samples were taken from 3 treatment areas at the mother plot. These were: (*i*) from the adjacent bare area where no *D. spicata* or any other significant vegetation grew; (*ii*) from the spreading margin of the grass where it was estimated that *D. spicata* had been growing for 2 years; and (*iii*) where *D. spicata* had been growing for 8 years. A second control was taken a further 5 m downslope of the main control to see if there was any major gradient in soil EC values down the slope. The sand plain and flats sites were only sampled in 2005 with destructive samples at 0–0.10, 0.10–0.20, and 0.20–0.30 m depths, with 5 replicated profiles being sampled from the 5-year-old *D. spicata* sward, and the adjacent control areas. The sand plain site did not have water-stable aggregate analysed due to difficulty in obtaining aggregates from the samples after they had been collected. Destructive samples from 2006 were only used for EC determination to provide a second year of comparative data.

The intact cores were used for saturated hydraulic conductivity and root density measurements, while the destructive samples from 2005 were used for determination of water-stable aggregates, pH, electrical conductivity, and soil carbon and nitrogen.

Soil measurements

Saturated hydraulic conductivity was measured on intact soil cores by the constant head method of Klute and Dirkson (1986), with cores being stored in a cool room before analysis. Roots were recovered from the soil cores after the measurements of hydraulic conductivity, by washing the sample, and then the root length measured with a Win Rhizo root scanner. Roots were then dried at 70°C until a constant weight was achieved. Water-stable aggregate measurements involved the random selection of 10 air-dried aggregates (10 mm in diameter) from each of 4 replicates from each treatment. These aggregates were wet-sieved in distilled water at 34 r.p.m. with a stroke length of 20 mm for a period of 5 min through 2, 1, 0.5, and 0.25 mm sieves. These sieves were then dried in an oven at 120°C for 1 h and the retained dry aggregates on each sieve were weighed to determine the mass of aggregates of different sizes. Soil texture was determined mechanically for each soil depth, and the results used to correct for the sand particles and gravel component.

Soil carbon and nitrogen were analysed by dry combustion using a CNHS auto-analyzer (Elementar, Varios EL). Soil was prepared by air drying, and then sieving to pass through a 2-mm sieve. Only 3 replicates were used for carbon and nitrogen analysis, unless large variation was found, where the full 6 replicates were used. Soil electrical conductivity and pH were measured in a 1 : 5 soil : water solution, after 5 g of air-dried soil was shaken for 1 h with distilled water. Standard errors were calculated for the mean values for each soil measurement for each soil treatment (*D. spicata* age, soil depth, site).

Results

The growth of *D. spicata* for 8 years showed a much greater root length per soil volume at all depths up to 0.26 m when compared to the control and the 2-year-old swards (Fig. 2). Although there was no difference in root lengths between the control and 2-year-old sward in the top 0.06 m, the 2-year-old sward had a greater root length at depths of 0.10–0.16 and 0.20–0.26 m. The control area, where no *D. spicata* had grown, had virtually no roots at 0.20–0.26 m. Root dry weights followed a similar pattern to root lengths at all depths, with the greatest mass of roots occurring where *D. spicata* had been growing for 8 years. Again, the greatest mass occurred in the top 0.06 m of soil across all treatments.

Concentrations of soil carbon and nitrogen in the mother plot were generally higher in the topsoil, and then decreased with depth down the soil profile (Fig. 3). However, soil carbon in the topsoil almost doubled in concentration to 0.75% after 8 years of *D. spicata* growth, compared with 0.40% for the control treatment. Smaller increases in soil carbon were also seen down the soil profile where there had been 8 years of growth. Two years of *D. spicata* showed a trend of higher soil carbon levels, compared with the control. Soil carbon concentrations tended to be higher at all depths (0–0.30 m) where *D. spicata* had grown for 5 years in the sand plain site; however, at the flats site soil carbon was similar within the 0–0.10 and 0.20–0.30 m depths, and lower where *D. spicata* had been growing for 5 years at 0.10–0.20 m depth (Fig. 3).

Concentrations of N in soil followed a similar pattern to soil carbon at all sites, with 8 years of growth at the mother

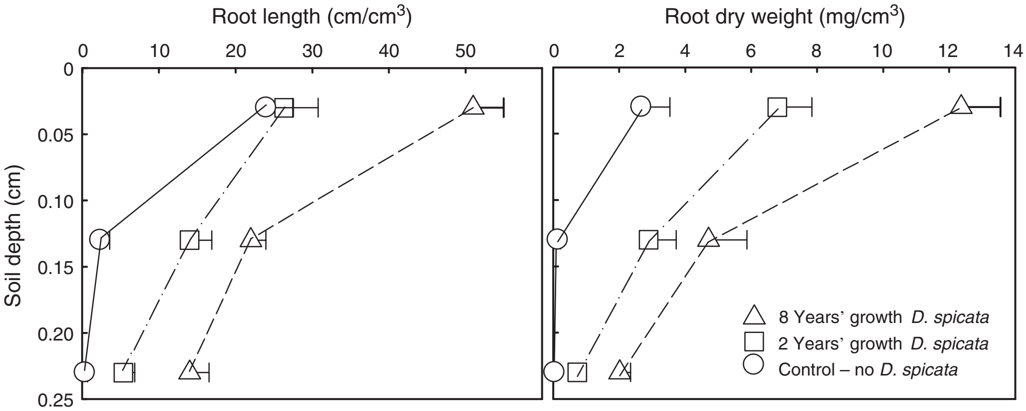

Fig. 2. Effect of growth duration of the *D. spicata* sward on plant root length and root dry weight of all plants at various depths. Root lengths measured include all roots (dead and alive) within the sample regardless of species. Error bars represent one standard error of the means ($n = 6$).

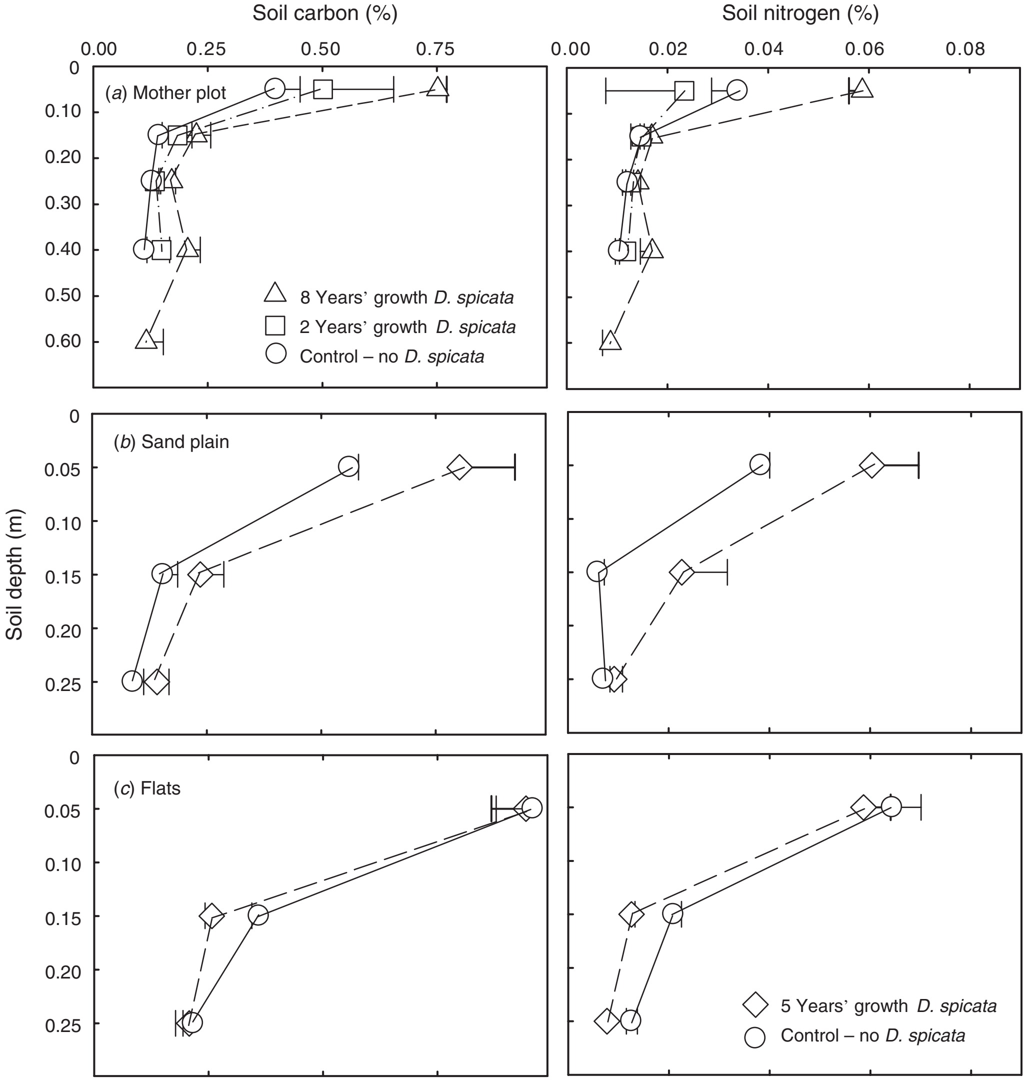

Fig. 3. Concentrations of carbon and nitrogen in soil layers where *D. spicata* has been grown for 0, 2, 5, and 8 years in saline discharge sites. Error bars represent 1 s.e.m. ($n = 3$–6).

site showing increases in the topsoil (Fig. 3). However, these differences were not evident at depths of 0.10–0.20 and 0.20–0.30 m and there were no increases in soil nitrogen where *D. spicata* had grown for 2 years.

Aggregate stability in the top 0.10 m of soil was increased with 8 years of *D. spicata* growth (Fig. 4). Almost three-quarters of the remaining aggregates were >2 mm in diameter after wet sieving. Similarly, more large aggregates >2 mm occurred in the 0.10–0.20 m soil layers, after 8 years of growth, compared with the 2-year area. There were no differences between *D. spicata* treatments for soil aggregates in the 0.20–0.30 and 0.30–0.50 m soil layers. The flats site (Fig. 5) showed similar results to the mother plot with a trend of more aggregates remaining >2 mm in diameter in the 0–0.10 m layer; however, there was a large amount of variation within the control site. There were no significant differences in aggregates <2 mm in diameter between treatments at any site (data not presented).

The growth of *D. spicata* had a marked effect on the saturated hydraulic conductivity in this soil, particularly in the surface layer (Fig. 6). Where *D. spicata* had grown for 8 years, the saturated hydraulic conductivity values in the surface 0–0.06 m layer increased 12-fold from 0.6 cm/h in the control to 7.4 cm/h. Two years of *D. spicata* growth resulted in more than a 3-fold increase in saturated conductivity values to 2 cm/h in the surface layer.

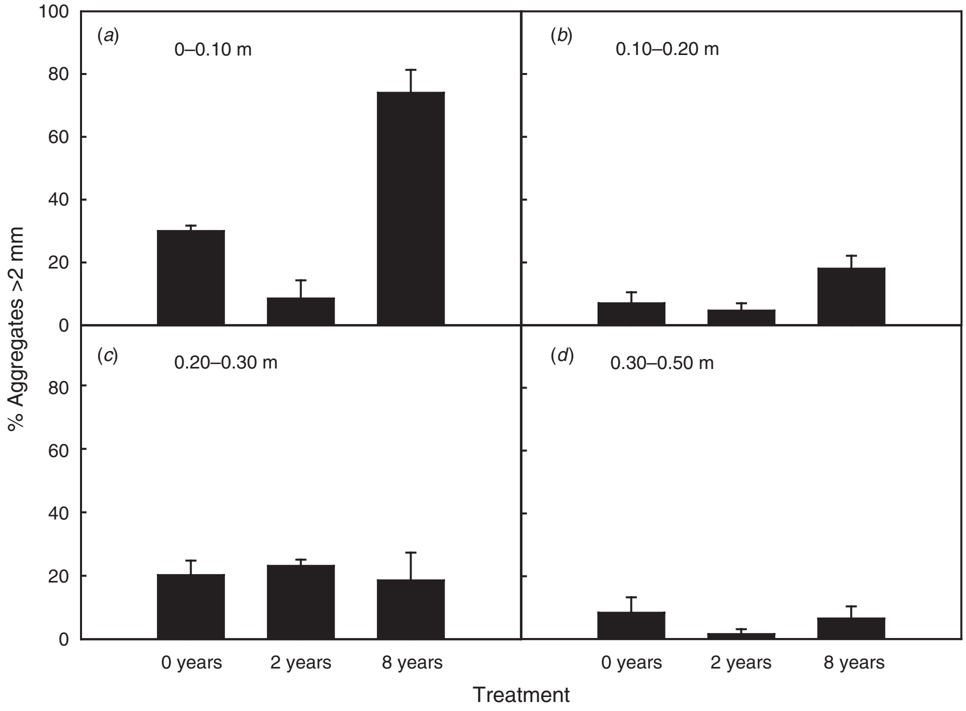

Fig. 4. Effect of growth duration of *D. spicata* on the percentage of water-stable aggregates >2 mm in diameter after wet sieving, in (*a*) 0–0.10 m, (*b*) 0.10–0.20 m, (*c*) 0.20–0.30 m, and (*d*) 0.30–0.50 m soil layers. Error bars represent 1 s.e.m. ($n = 6$).

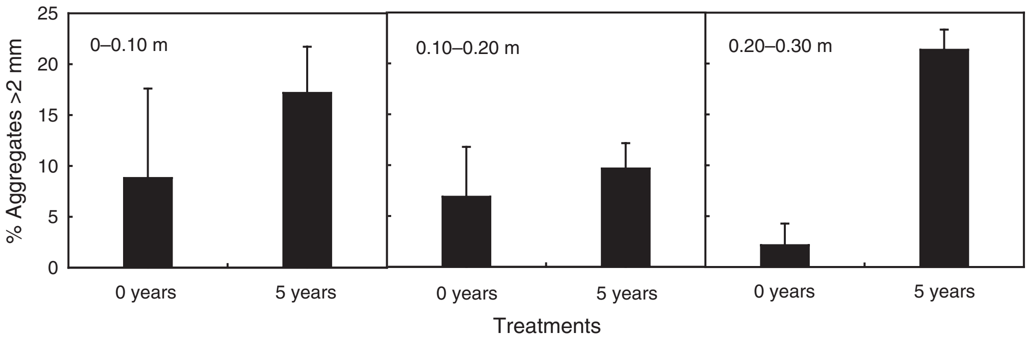

Fig. 5. Effect of 0 and 5 years of *D. spicata* on the percentage of water-stable aggregates >2 mm in diameter after wet sieving in 0–0.10, 0.10–0.20, and 0.20–0.30 m soil layers. Error bars represent 1 s.e.m. ($n = 5$).

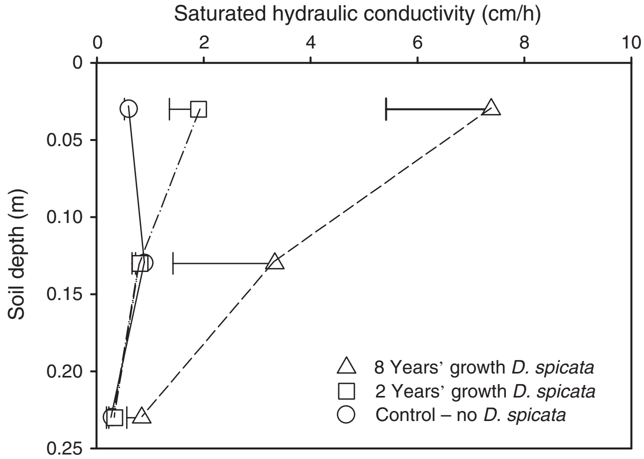

Fig. 6. Effect of *D. spicata* growth duration on the saturated hydraulic conductivity of the soil at varying depths in the soil profile. Error bars represent 1 s.e.m. ($n = 6$).

The effect of *D. spicata* growth on the saturated hydraulic conductivity decreased down the soil profile (Fig. 6). There was a 4-fold increase from 0.90 to 3.30 cm/h after 8 years of growth in the 0.10–0.16 m soil layer, and only a small effect of *D. spicata* growth on the conductivity in the 0.20–0.26 m soil layer where values doubled from 0.5 cm/h in the control soil to 1.0 cm/h after 8 years of growth.

Electrical conductivity in the soil profile was also affected by *D. spicata* growth at the main sampling site in the mother plot at the Wickepin discharge site (Fig. 7). In the wetter winter of 2005, electrical conductivity was lower in the top 0.50 m of the profile where *D. spicata* had been growing for 2 and 8 years, compared with the control soil where no growth had occurred. The reduction in conductivity was most marked in the surface 0–0.10 m layer where conductivity was halved from 1.6 to 0.8 dS/m, for both *D. spicata* treatments. Electrical conductivity increased in the 0.30–0.50 m layer, but was still lower with the *D. spicata* treatments than the control.

In the drier sampling period in the winter of 2006, *D. spicata* treatments continued to have lower electrical conductivity values in the 0–0.10 m surface layer (Fig. 7) compared with the control area. The effect was greatest where *D. spicata* had been growing for 8 years, with a 50% reduction in electrical conductivity compared with the control soil. Electrical conductivity in the 0.10–0.20 and 0.20–0.30 m layers was similar between the treatments.

Electrical conductivity at the additional sites showed differing results (Fig. 8). At the flats site (A), the electrical conductivity under the *D. spicata* was similar to the control in the topsoil, but was higher than the control below 0.10 m. At the sand plain site (B), electrical conductivity in the topsoil under the *D. spicata* was lower than the control, but was similar in the 0.10–0.20 and 0.20–0.30 m layers.

Discussion

The present field survey has indicated that *Distichlis spicata* var. yensen-4a has the ability to actively grow and expand in area in saline and seasonally waterlogged soils in the survey area within the wheat-belt of Western Australia. Commercially available species that are suitable for agricultural production in saline areas within Australia are limited to *Atriplex* spp. (salt bush), *Puccinellia ciliata* (puccinellia), *Thinopyrum ponticum* (tall wheat grass), and *Distichlis spicata* var. yensen-4a (NyPa Forage). Of these species, *P. ciliata*, *T. ponticum*, and *D. spicata* are all suited to saline waterlogged soils. However, as *D. spicata* is the only C4 species, it is the most suited to the high temperatures and high radiation regimes during the warm summer months of southern Australia. This species not only has the ability to grow and spread in saline waterlogged soils, but also produces valuable green feed in moist saline discharge soils during the summer period. Such forage has real value for a mixed farming system in the region where conserved fodder or grain are required to maintain sheep liveweights through the summer period (Leake *et al.* 2002).

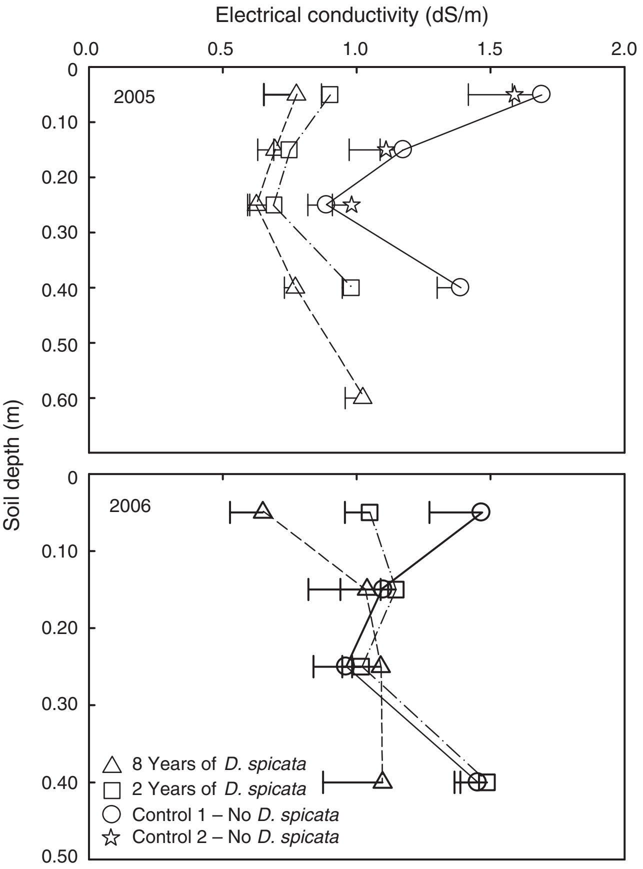

Fig. 7. Effect of 0, 2, and 8 years of *D. spicata* growth on the electrical conductivity (1 : 5, soil : water) at increasing soil depths, in 2005 and 2006 at the main sampling site at Wickepin discharge site. Control 2 is located 5 m down slope of control 1. Error bars represent 1 s.e.m. ($n = 6$).

The present field survey has confirmed that *D. spicata* has the ability to improve the soil chemical properties at this saline site, as initially suggested by the landholder. Improvements occurred particularly in the surface soil, but to a lesser extent in subsoil layers. Most of the root growth occurred in the topsoil (Fig. 2), with 8 years of growth producing the highest root length density and root dry matter. These roots periodically die, and over time

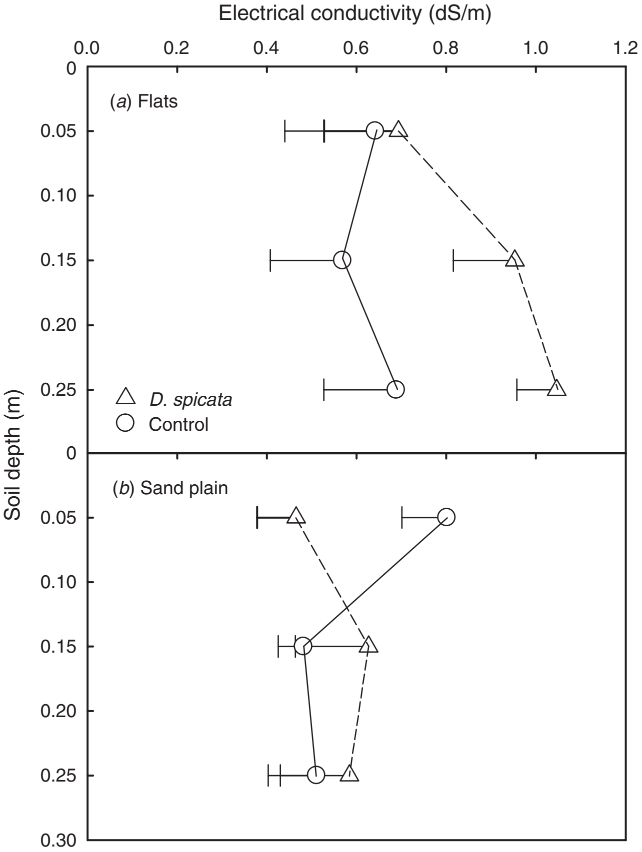

Fig. 8. Effect of 5 years of *D. spicata* growth on electrical conductivity (1 : 5; soil : water) at increasing soil depths, at (*a*) the flats site and (*b*) the sand plain site at the Wickepin saline discharge area. Error bars represent 1 s.e.m. ($n = 5$).

add organic matter to the soil matrix. The subsequent breakdown of this organic matter within the soil added organic carbon and increased the nitrogen status of the soil (Fig. 3).

Distichlis spicata var. yensen-4a was also shown to improve the soil physical fertility, with increases in saturated hydraulic conductivity and aggregate stability (Figs 4–6). These improvements in soil physical properties are most likely due to the increased root growth and turnover throughout the soil profile. It has been shown by other researchers that soil structure improves with increasing root growth (Perfect *et al.* 1990; Haynes and Francis 1993). In addition, Bruce *et al.* (1992) showed a positive relationship between soil carbon and aggregate stability. In this survey, the increase in stability of large aggregates (>2 mm) in the top 0.10 m can be attributed to the increased organic matter from the root activity and associated biological activity, which is consistent with the findings of Clarke *et al.* (1967), Forster (1979), and Tisdall and Oades (1982). Similarly, the increase in saturated hydraulic conductivity throughout the soil profile can be attributed to the root activity of *D. spicata*. The periodic turnover of roots within the profile leaves old root channels, which, along with the increased aggregate stability, contribute to the improvement in the physical structure of the soil, and hence increase the saturated hydraulic conductivity.

The soil electrical conductivity appears to have been reduced in the surface layers of the soil where *D. spicata* had been growing for 2 or 8 years (Fig. 7). Fourteen months later in September 2006, when the soil was drier and less waterlogged, electrical conductivity in the topsoil occupied by *D. spicata* was half that of the control soil (Fig. 7). However, caution is required with these measurements as there was a physical slope at the site that would enable the lateral movement of water through the soil from the area where *D. spicata* was growing to the control area. This was noted at the time of sampling, and a second set of samples from the control soil was taken further down the slope (which appear as control 2 on Fig. 7). It can be seen in Fig. 6 that this second control is similar in conductivity to the first control, suggesting that any salinity gradient down the slope was minimal within the sampled area. One could therefore argue that *D. spicata* has been able to decrease soil conductivity within the topsoil across all years sampled at all sites (Figs 7, 8). Such a claim is very tentative for 2 reasons. First, we lack baseline conductivity measurements prior to *D. spicata* being established at the site. A second reason is the large spatial and temporal variation in the data and between years. Such spatial and temporal variation in soil electrical conductivity in saline discharge sites has previously been documented by Semple and Koen (2004).

The findings from this survey generally support the proposition that growth of *D. spicata* does not lead to an accumulation of salt in the subsoil. The most convincing data are presented in Fig. 8*b*, where there are parallel downslope treatment soil samples; one set was taken under 5-year-old *D. spicata*, while the second was taken from the control area where no *Distichlis* was growing. Low electrical conductivity values occurred in the topsoil layer under *Distichlis*, with no accumulation in electrical conductivity in the subsoil layers under *Distichlis*. The lower subsoil electrical conductivity value under *Distichlis* in the mother plot, and the high electrical conductivity value under *Distichlis* in the flats, are both confounded by the positioning of the control area relative to the *Distichlis* plot. In both instances, high electrical conductivity values occurred in the subsoil in the downslope plots, suggesting that salt had moved to subsoil that was lower in the landscape.

We therefore conclude, on balance, that there has been minimal accumulation of salts within the rooting zone of *D. spicata*. This contrasts with the accumulation of salts within the root-zone of *Atriplex* species (Barrett-Lennard and Malcolm 1999), which raises questions about the long-term sustainability of systems that are based on *Atriplex* species. Further study is required to directly compare salt dynamics in the rooting zone under current cultivated halophyte species in the field.

In conclusion, the work presented in this paper demonstrates that *D. spicata* is capable of improving the chemical and physical fertility of a saline and seasonally waterlogged soil within the survey area in the wheat-belt of Western Australia. These improvements are consistent with the results of research conducted in Pakistan, where the salt-tolerant Kallar grass (*Leptochloa fusca*) was shown to improve the physical properties of saline-sodic soils (Akhter *et al.* 2003, 2004). The question about sustainability of *D. spicata* swards in saline discharge sites can also be laid to rest, with the data indicating that salt is not accumulating in the root-zone. Thus, the use of *D. spicata* in saline and seasonally waterlogged sites is a productive option for landholders as a way of utilising an otherwise abandoned unproductive land. The improvements in soil physical and chemical properties, along with the summer production of green forage, make *D. spicata* a very useful species for these salinised soils.

Acknowledgments

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