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The role of NyPa *Distichlis spp.* cultivars in altering groundwater & soil conditions, (updated in 2016)

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Summary
This paper reports the results of work carried out to investigate the role of economically useful cultivars of *Distichlis spp* in the rapidly growing areas of agricultural, mined and urban land afflicted with land salinity from saline water. It reviews work in the USA and Mexico with swamp grasses, explains how they are able to thrive in wet saline environments and how some have been selectively bred for different purposes. It briefly reviews work being undertaken in Australia to evaluate the productive uses of the plants under different climate, soil and water conditions and discusses the impact of the plants on water use, salt movement, soil structure and drainage. It is concluded that these NyPa *Distichlis spp* halophytes (salt loving) grasses warrant consideration as a cost effective means to address degraded land areas where saline water exists, both with to restore some productive use, and for rehabilitation on a stand-alone basis, and to reduce the cost and improve the effectiveness and sustainability of engineering approaches to reducing saline discharge areas by drainage.

1. INTRODUCTION
There is a thriving but somewhat sterile debate about the relative merits of plant-based versus engineering solutions to the negative impact of rising saline groundwater on agricultural and urban lands, and other salty land resulting from human activity. The purpose of this paper is to discuss the plant mechanisms that enable some plants to survive indefinitely in such sites and to speculate about the ability of some of these plants to reverse the processes that have led to these difficulties in some areas. Based on results from work in Southern Australia and in the USA, the paper suggests that plants and engineering solutions are not mutually exclusive, and may have applications in a wide range of situations where salt water and soils have been impacted by rapid human-induced change, at least in conditions of high sunlight.

2. PLANTS AND SALINE ENVIRONMENTS
The mechanisms by which plants tolerate saline conditions are multifaceted, related to whole plant responses and not well understood (Tanji 1990[i]). Most plant breeding and plant domestication work has been carried out on plants adapted to fresh water, so called ‘glycophytes’, and well drained sites (a relevant exception being rice which is adapted to wet sites). This may be because the selection process probably began accidentally around human settlements that are necessarily located near fresh water (Yensen 2002)[ii], or because salt tolerance requires plant energy, which is thus less available for a by-product useful to humans. However, early forms of plant life may have begun in shallow saline areas and some have retained these evolutionary adaptations. Although several halophytes are highly productive, such as mangroves, few now produce much of value to humans.

Wet saline areas are, by contrast to the areas cultivated by humans, poorly drained and, in dry climates, highly saline. Salts are toxic to cellular processes at higher concentrations and plants that have naturally adapted to these sites have one or more of these characteristics:

- developed cellular processes to partition salt into vacuoles or to exclude salt at the root zone so it does not impact on cell growth (Waisel 1972) & (Hansen et al 1976[iii]);
- evolved *aerenchyma* tissue, which contains spaces in the roots that permit gas exchange in anaerobic conditions (a quality possessed by rice). See Photo 1 below;

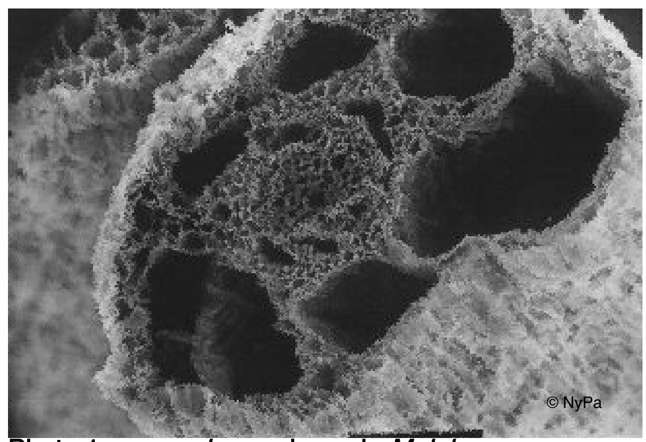


Photo 1: ***aerenchyma*** **shown in** ***Melaleuca halmaturorum*** (Atwill (eds) et al 1999[iv])

- salt glands that enable partitioned salt to be exuded at the leaf surface (Hansen et al 1976) & (Liphschitz et al 1982[v]);
- a poorly understood capacity to utilize light energy for carbon sequestration and respiration in salty environments (Kemp & Cunningham 1981[vi]);
- a deep root structure that provides drought resistance and a means of colonising salty marsh regions (Hansen et al 1976);
- patterns of growth and regrowth whereby the rhizomes periodically senesce and die leaving behind drain lines filled with dead organic matter while new roots grow nearby; a cumulative process known as a *rhizocanicular percolation effect*, which over time creates or

restores soil structure and drainage (Yensen 2001[vii]).

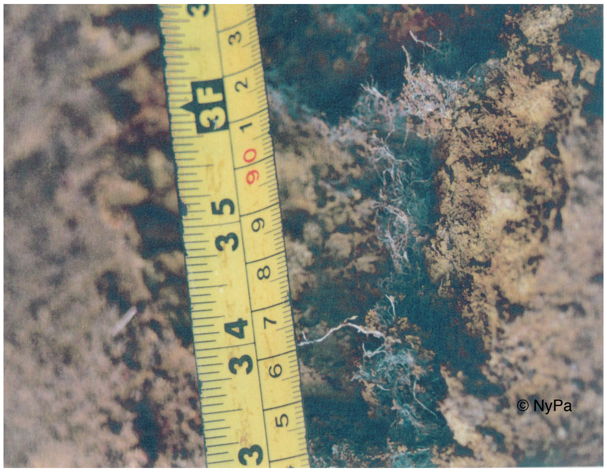


Photo 2: Rhizocanicular effect - detail at 1 metre, WA

It is suggested here there is an important difference between salt tolerant plants that develop a passive tolerance to periodic salinity and those that actively modify their root environment to facilitate their survival and spread. The importance derives from the consequent soil restoration effect. Almost all plants adapted to desert regions have necessarily retained or developed a capacity to tolerate fluctuating salinity. Many restrict salt intake at the root zone but this requires periodic flushing with fresh (rain) water to survive. Some plants such as *Puccinellia ciliate* have evolved shallow root structures that enable more regular flushing from light rain and exhibit some *aerenchyma*. These do not move the salt but rather 'live with it', and provide some useful grazing while breaking up the feedback process of salt deposition that leads to salt scalds.

Plants that modify their root environment such as salt bush (*Atriplex spp)* are able to use salty water for respiration indefinitely by passing some salt through their system. Ferdowsian has shown salt bush is able to mimic the original native vegetation in maintaining the saline water table below the capillary fringe in some areas of the broad valley bottoms of the Western Australian wheat belt, thus ultimately reducing salt deposition (Ferdowsian et al 2002[viii]). The NyPa grasses pass virtually all of the salt though their leaves as discussed below.

However most deep rooted halophytic plants do not tolerate the anaerobic conditions of wet saline sites, and without an effective salt gland are not particularly efficient at moving this salt out of the plant again, which limits respiration and so production in conditions of high salinity in the groundwater. This is an important consideration in the salt water discharge zones associated with dry land salinity, in urban areas where leakage below lawns and gardens are creating saline water mounds that damage infrastructure, and in some oil polluted sites or degraded mine sites where salinity is inhibiting rehabilitation.

Distichlis spicata is a particularly successful adaptation to wet sites that have become inhospitable to most plants due to salinity. The species has adapted to a very wide climatic range from Canada to South America (there is even a relation that crossed the pacific to Hawaii and Australia, *Distichlis distichophlla*), but is particularly successful in hot littoral regions such as the Gulf of California, and marsh areas where salt continues to accumulate through drainage and evaporation, at least where the salinity does not exceed ocean levels. Yensen selected and patented a variety of *Distichlis spicata* having desirable leaf growth qualities for forage[ix], a subsequent selection in Australia was granted plant breeders rights as also having these qualities, a similar result in Spain has resulted in plant breeders rights being issued for the EU also.

While it is the *integration of responses in the whole plant* (to quote Tanji 1990) that is probably responsible for the *Distichlis spp* capacity to survive in highly saline sites, they possess two of the characteristics that enable it to modify a saline environment to an exceptional degree:

- their bi-cellular salt gland, the mechanism by which they pass salt through their system during respiration, is at least twice as efficient (in the sense of salt secreted over internal salt content) as the next nearest competitor (*Aeluropus litoralis*) according to Liphschitz et al, and almost 100 times as efficient as species thought of as having some productive use of benefit to humans such as *Paspalum spp* (Liphschitz et al 1982);
- its rhizocanicular percolation effect is particularly pronounced, providing measurable net gains in drainage to previously impacted soils in serial biological concentration of irrigation drainage water projects in USA (Yensen 2001 & Sargeant 2006[x]).

Photo 3: Rhizocanicular percolation effect - new soil structure to the water table. Wickepin, WA

3. WORK IN USA AND MEXICO

Speculation appeared as early as 1956 that *Distichlis spp* might be selected for productive use in saline marsh areas, based on its drought and salinity tolerance and reserve feed value (Nielson quoted in Hansen 1976), although little was done until Yensen began in 1975. He focused initially on the grain variety *Distichlis palmeri* (NyPa 'Wild Wheat®' granted the first US patent for a plant in 1988[xi]), and from the 1990's on its value as forage and turf. He undertook a breeding program with hundreds of plants collected from all over the USA and Mexico and selected one that exhibited qualities as productive and nutritious forage (NyPa™ Forage) and another showing qualities as a drought resistant, low growing turf (NyPa Turf). Work on the nutritive value and production resulting from these selections is reported in Yensen for the US (1998) and Sargeant for Australia 2008[xii]).

Work in the USA on these two varieties has focused as much on their use in land rehabilitation as their productive use. Work in the San Joachim valley in California has shown its value as a constituent part of systems to concentrate drainage effluent water prior to disposal thus reducing pumping costs while providing valuable fodder and improving infiltration (Cervinka et al 1999[xiii]). This is part of a systems approach to the disposal of saline groundwater that features the recovery of valuable products from each stage of concentration of the water from a mildly saline effluent, to hyper-saline water or salt for economic disposal. The system is known as Serial Biological Concentration (SBC) and is being investigated in several parts of Australia. This work in California has also shown how *Distichlis spp* can provide a source of organic feedstock for algae, the basis of food supply for Artemia, another part of a SBC system.

Photo 4: NyPa Forage hay, San Joaquin Valley California

More recent work in the US has focused on the use of the forage in the rehabilitation of land degraded by saline water associated with oil drilling in Arkansas and Oklahoma[xiv]. Here the plant was grown in bituminous, oil soaked saline land to 'open it up' to drainage and allow natural microbiological processes to act on the impacted bituminous residues of oil exploration in the early parts of the last century (Yensen et al 2002[xv]). Other work in the US has been undertaken by the Musco Family Olive Co, to enable disposal of saline effluent from Olive processing, mainly by Hall B[xvi]. It has been noted that *Distichlis spicata* is highly tolerant of heavy metals and a range of salinities from acid to highly alkaline (Prodgers & Inskeep 1991)[xvii] and able to secrete a wide variety of salts, important in mine site rehabilitation.

4. EVALUATION IN AUSTRALIA

Work with *Distichlis spp* in Australia, begun in 1994, confirmed that the four 'domesticated' varieties would grow and produce valuable products. Two of these, NyPa™ Forage and NyPa Turf have been assessed as having a low weed risk relative to other introduced salt tolerant grasses, as they are male 'clones' and reproduce only vegetatively and in saline conditions (Virtue et al 2002[xviii]). One of the others, *Distichlis palmeri* was selected as a high yielding cereal grain variety, while the fourth was a high seeding variety (since discontinued). The purpose of the work was to evaluate the plants for productive use in rehabilitation of highly saline sites in WA, SA and Victoria (Leake et al 2002[xix] and Sargeant 2003[xx] Sargeant 2009).

Photo 5: *Distichlis* NyPa forage in a salt pan, WA, 20 years ago this was the most productive Salmon gum wheat fields (Mathews 2004)[xxi].

5. METHODS

The methodology in Australia followed standard approach to investigating a new species. Information was gathered from observation trials to provide a basis for further analysis while enabling decisions to be made as to the uses to which *Distichlis spp* might be put within Australia and the methods of commercialization. The initial trials were established in the three southern states and were followed with more detailed glasshouse investigations and analysis of the nutritional qualities of the forage and the milling qualities of the grain. The work is ongoing and new work to study the use of the NyPa Turf in urban landscapes has

commenced, while work to investigate the use of all the plants in SBC systems is in on going, particularly in Western Australia.

6. RESULTS

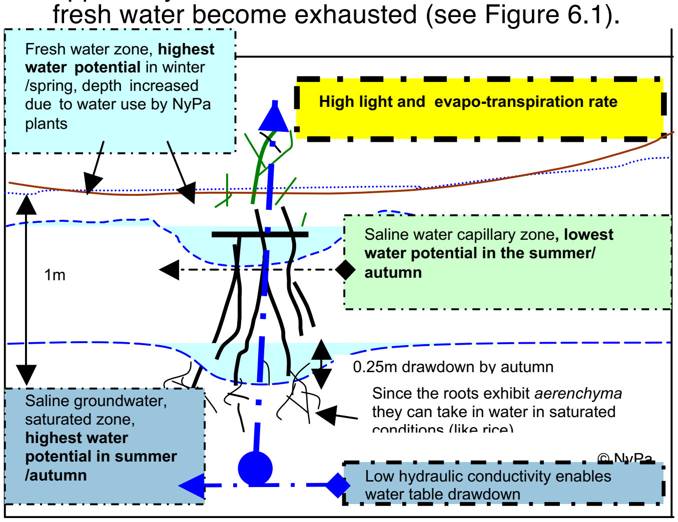
The Australian work reported here addressed both the productive and environmental impact of the use of *Distichlis spp* in saline discharge areas. The ecological range in Australia was estimated to be where saline groundwater of between about 10 mol/m^3 salinity up to almost 1.5 times ocean water salinity (800mol/m^3), within about one metre of the surface. The plants grew most actively in conditions where the temperature was above 27°C, in bright sunlight and where the groundwater contains salt.

The Forage was observed to yield up to about 25MT green matter (13.5 MT/ha dm) of forage with a protein content of between 5% and 17% and with a digestibility of between 45% and 60% with the best results to date in WA. This concurs with results in the USA and Mexico (Yensen 1998). The results in Australia were variable and depended on nutrition and on other factors not yet well understood (Leake et al 2002), replicated by Lymbery A .

The *Distichlis* grain exhibited similar growth characteristics in Australia as in the USA, Mexico and Morocco sites (Yensen 1998), and is the subject of a current study assisted by AusIndustry to prove its future as a commercial cereal crop in Australia.

The results relevant to the impact of the *Distichlis spp* cultivars in Australia on groundwater conditions were as follows:

- in each state of Australia, the plants were observed to send roots down between one and two metres until the plants had reached the saline water table where they developed a fine-hair root structure, through which the plants apparently draw saline water when stores of fresh water become exhausted (see Figure 6.1).



(Leake et al 2002)

Figure 6.1 Plant access to a saturated saline aquifer

- in each Australian state the roots displayed the rhizocanicular effect noted in the USA and Mexico and, based on observation, this gradually improved soil structure and organic content. This is shown in Photos 2 and 3 above. It was noted that at this site worms re-occupied the soil within three years of establishment of *Distichlis*;
- in all states, observations suggested the plants used significant saline water when growing actively, particularly in the summer. Near Wickepin Western Australia, anecdotal evidence suggests that the plant was able to depress and hold the water level to about half a metre below the surrounding land in an area where water normally seeped from the surface in winter;
- in each state, the plants have been observed to exude salt at the leaf surface. This seemed to be in proportion to the rate of growth, which was proportional to temperature.

Photo 6: *Distichlis* NyPa Forage with salt on leaves

7. DISCUSSION

7.1 Water use

As discussed above, it has been suggested that salt bush (*Atriplex spp*) is able to mimic the native vegetation in its capacity to keep the saline aquifer below the capillary fringe in the broad valley bottoms of the WA wheat belt where there is little lateral movement of the aquifer. However, salt bush is not able to perform this service in regions that are frequently waterlogged, as the anaerobic conditions in saturated zones limit growth of such plants (Barrett Lennard 1986[xxii]). It was also noted that production, and so water use, is reduced when the water table moves appreciably below the root depth (Ferdowsian et al 2002).

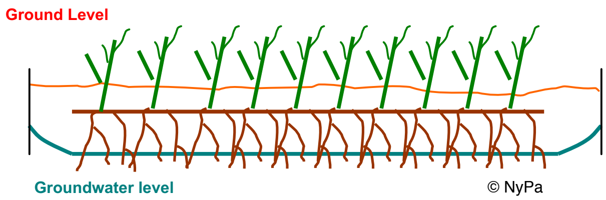


Figure 7.1: Diagram suggested by Ferdowsian to illustrate impact on broad valley bottoms in the WA wheatbelt (Ferdowsian 2002 pers comm).

Distichlis spp compliments this capacity of salt bush in the most active discharge zone, while providing very useful production in the summer months when little grows. Figure 7.1 illustrates how this impact can occur on a landscape scale. Their deep root structure (up to 2 metres) combined with *aerenchyma* is an unusual combination which provides the plants with the capacity to access saline groundwater in the saturated zone, at least when fresher surface water is not available. The mechanism by which the plants are considered to be able to access this saline water from the saturated zone is depicted in Figure 6.1. In such saturated zones the *Distichlis spp* plants growth is not limited by access to water.

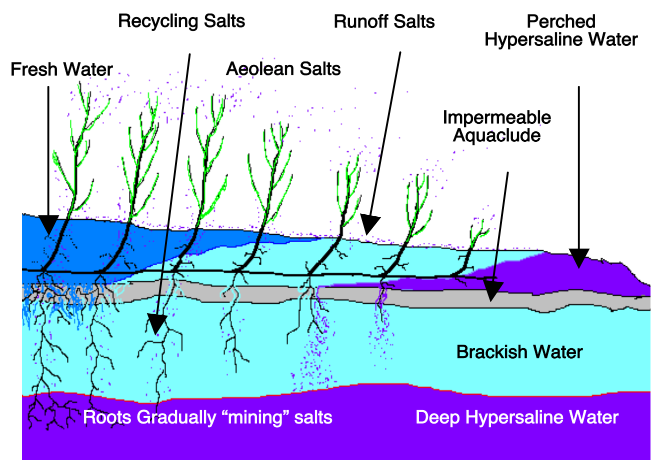
As discussed above, the existence of the plant's efficient salt gland is also fundamental to the plant's capacity to transpire and grow effectively in saline water. It seems from observation that the plant draws all or most of the salt in the water it uses through the plant and exudes it to blow away or drop to the ground. Thus salt does not seem to accumulate in the root zone (Sargeant 2009)[xxiii]. This impact on salt movement is discussed further below.

The quantity of water used by the plant has also not been measured definitively for any particular site but, as stated, has been observed to depress the aquifer at the Wickepin site where the surface used to be damp at almost all times. It is suggested that, where the plant has access to permanent saline groundwater, its water use will be a function of the Annual Point Potential Evapotranspiration[1] (ET potential) modified by actual temperature (since *Distichlis spp* is known to perform better at temperatures over 27°C) and the salinity content of the water (since salt binds water requiring more energy for evaporation to occur).

Wickepin has an average annual point potential ET of 1800 mm pa. This represents the maximum amount of soil water that a crop could evapo-transpire over a year given an unlimited supply of fresh water to the crop. This limit is determined by the latitude of Wickepin (incoming solar radiation) and climate factors. The actual average annual ET for Wickepin is 300-400 mm pa. This represents the actual amount of fresh water that a crop will evapo-transpire, given the limited availability of water (rainfall). Now in addition to the usual soil moisture store, *Distichlis spp* has access to an additional source of soil water, namely saline groundwater. Thus, the actual ET will be higher than 300-400 mm pa, but it will be less than 1800 mm pa because of the extra energy required to move saline water through the plant. For the sake of demonstration, assume that the actual ET is the average of these two limits, say 1000 mm pa at this site.

7.2 Salt Movement

The implied salt movement is also very significant. The salinity of groundwater at Wickepin where plants are growing well lies between 10,000 mg/l and 20,000 mg/l. Adopting a middle limit, actual ET by *Distichlis spp* at Wickepin of say 1,000 mm pa, may be moving some 10- 15 kg of salt per cubic metre of saline water respired from the groundwater to the leaf surface per year. Depending on the hydraulic conductivity of the soil, the density of the stand and assuming roots are continually in saturated soils (see figure 7.1) this volume of water may be drawn from close to a square metre, implying a salt movement approaching 100 tonne per ha. By observation the movement is considerable, see photo 5.0 above.



(Yensen et al 2002)

Figure 7.2 Salt Flow Possibilities with *Distichlis spp*

Where is all this salt going? Some is clearly rejoining atmospheric salt movement. Something between 4.2 (desert inland) or 12.9 kg (Eriksson 1958[xxiv]) and 730 kg (Waisel 1972[xxv]) of salt per ha per year falls on the land from atmospheric sources depending on distance from the coast and rainfall. Some of it washes into creek lines during significant rain events (as salt deposited on the surface is now moving) and some washes back into the ground as the *Distichlis spp* plants modify the drainage (this impact on drainage is discussed below).

[1] *The Bureau of Meteorology defines point potential Evapotranspiration (ET) as the ET that would take place, if there was an unlimited water supply, from an area so small that the local ET effects do not alter local air mass. It is assumed that latent and sensible heat transfers within the height of measurement are through convection only.*

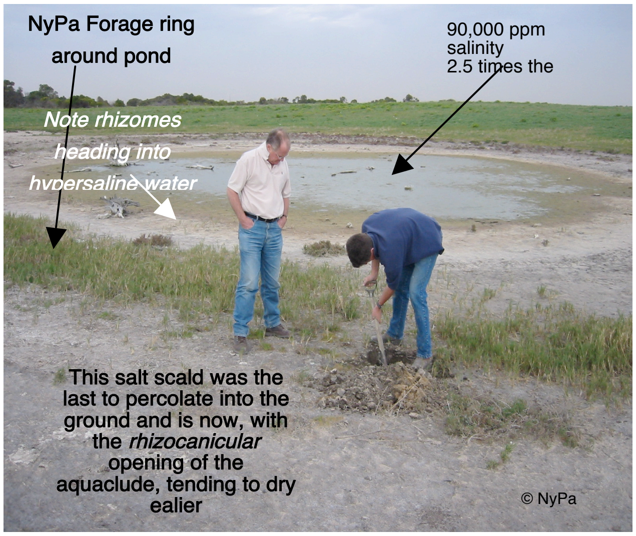


Photo 7: Meningie, South Australia 2002

The salt movement possibilities are depicted in Figure 7.2. The net change in salt movement in a site is clearly related to and less than, the net change in water use and will vary between different locations depending on wind, humidity, rainfall and soil structure. This may be considered as either a significant speeding up of the process of ridding the landscape of the salt emerging at the surface from rising saline groundwater (as in WA), or a reversal of the process where salt deposited on slopes washed down into lower lying areas when the vegetation was cleared in many other areas in Australia.

7.3 Drainage Changes

The rhizocanicular percolation effect on soil structure appears to be cumulative and to have different impacts depending on clay content and the degree to which the clays have flocculated due to the salt. In sandy areas the impact is quite slight while in highly impacted former irrigation areas the effect takes some years to become apparent. The process by which we suggest these occur are depicted in Figure 7.3.

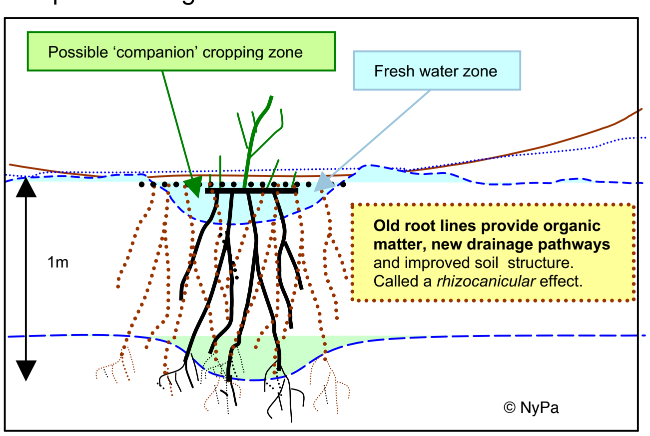


Figure 7.3: The rhizocanicular percolation effect, (Leake et-al 2002)

The impacts of the effect in different locations are suggested to include:

- in sandy areas, the soil above the lateral rhizome seems to lose its salinity so that fresh water plants are often seen to re-establish. This may point to the possibility of companion cropping with a winter active cereal, such as barley, or a water logging tolerant legume such as balansa clover (*Trifolium michelianum*). There is not much impact on drainage but worms and other organically active carbon processes increase markedly. This effect appears within a couple of years. The companion cropping idea has yet to be tested;
- in deeper impacted clay conditions, the full root structure takes several years to establish but the process enables the plants to colonise nearby clay areas where the plants did not originally establish, perhaps due to a higher salinity level or some nutrition deficiency. Drainage does improve where the drained water has an exit point from the site or where it can move down into a lower aquifer as a result of opening up the soil as depicted in Figure 7.3 and Photo 7;
- in former flood irrigated land where salt has resulted in deflocculated clay and reduced water infiltration, the effect has been seen to assist leaching salt from the site, although the effect of improving infiltration rates observed in Mexico has not yet been observed in former irrigated land in Australia, as this has not been measured.

7.4 Benefits - Financial and Environmental

The benefits from the use of plants adapted to saline environments, including the NyPa suite of plants, which have the additional benefit of restoring soil health, sequestering carbon and, in many circumstances, improving hydraulic conductivity, (drainage) are both economic, including environmental, and financial (Qadir E et al 2014)[xxvi].
The ecosystem services so provided, variously including, land restoration, saved fresh water, nutrient and other pollutant stripping and improved biodiversity conservation.

The main financial benefit of the use of the NyPa Forage is the production of green forage in the summer months when little else grows in the southern states without irrigation.

Observation trials of the NyPa Turf suggest that its main financial benefit will be the ability to grow an amenity grass using treated effluent water, or drained or pumped saline groundwater without deflocculating the clay and reducing infiltration. Indeed it seems likely that such sites will be rehabilitated by using this grass. The use of saline groundwater to irrigate the NyPa Turf will tend to reduce the damaging saline groundwater mounds and enable a saving in the use of valuable fresh water for this purpose, the use of which is now

building these mounds in many rural towns in Australia.

The main financial benefit of the use of the NyPa Wild Wheat will be the establishment of a new non-gluten high fibre cereal crop in some areas where cereal growing has ceased or is ceasing due to salinity.

These financial benefits would tend to reduce the cost of associated drainage.

8. CONCLUSION

It has often been observed that Australia's rapidly salinising landscape requires a rethink of our farming systems (e.g. Williams J Ex Head CSIRO Div. Land and Water). The use of deeper rooted perennial plants that can reduce aquifer recharge, halophytes in general, and the NyPa *Distichlis spp* plants in particular, offer an approach that may be implemented individually for financial gain while impacting positively on saline water discharge on a landscape scale.

The work is still preliminary but the indications are that the plants have uses in both plant-based attempts to use such land and water profitably and in engineering based efforts to reduce the water and salt loads. This is due to their impact on drainage and soil structure in both agricultural and urban settings.

9. ACKNOWLEDGEMENTS

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