

Irrigation with saline water

Can it add value to agriculture?



by Brad Stillard

2010 Nuffield Scholar

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Foreword

Many irrigators throughout Australia will know all too well the reality of drought and how valuable irrigated agriculture is during these times. When surface water allocations are exhausted the ability to draw water from an alternative source allows production to continue.

This report is sponsored by the Australian Processing Tomato Growers and Horticulture Australia Limited. It looks at using water supplies that are saline and examines the hazards that come with it and some of the methods used to avoid them.

All irrigation water contains salts (Adrol, Yadav & Massoud, 1988). It is this fact alone that makes understanding what those salts do to the soils they are applied to and the plants that grow in them important to any irrigator.

Predictions of a future with a reduction in annual rainfall, higher temperatures, demands from a growing population and environmental needs in Australia will all influence the share of surface water that agriculture will be permitted to use for irrigation.

The key findings contained in this report look at adopting successful strategies for the long term use of saline water with the goal of sustaining its use as a viable alternative to surface water. Tours through the Middle East and the United States of America (USA) set out to achieve this.

Developing farming practices and crop cultivars for saline irrigation will become one of the most critical issues in solving dwindling fresh water supplies and regaining the viability of land being lost to salinity.

The Nuffield Australia website contains further reading on the possible use of saline water. Nuffield Scholars Cameron Tubby (2009) and Neil Smith (2001) have both written informative reports that add to the question, can saline water add value to agriculture?

Acknowledgements

On receiving a Nuffield scholarship it quickly became apparent many scholars before me regarded a scholarship as a life changing experience. Indeed it is and I am very thankful to the board of Nuffield Australia and the state and federal selection panel for my inclusion in this once in a lifetime adventure.

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Abbreviations

AUD - Australian Dollar

CSIRO - Commonwealth Science and Industries Research Organisation

CTF - Controlled Traffic Farming

CT - Conservation Tillage

dS/m - deciSiemens per metre

EC - Electrical conductivity

EM38 - Electro Magnetic 38hMk2

FIGS - Focused Identification Germplasm Strategy

GPS - Global positioning system

ICBA - International Centre for Biosaline Agriculture

ICARDA - International Centre for Agriculture Research in Dry Areas

MDB - Murray Darling Basin

MDBA - Murray Darling Basin Authority

NSW - New South Wales

RO - Reverse osmosis

SDI - Subsurface drip irrigation system

t/ha - Tonnes per hectare

t/ac - Short tons per acre

TX - Texas

USA - United States of America

USD - American dollar

WANA - West Asia and North Africa

GFP - Global Focus Program

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Executive Summary

Saline water can be valuable to some, waste water to others. High levels or low, the presence of salt in water can potentially be harmful to crops and the environment. Predicted climate change is forecast to have a direct impact on water availability for irrigated crops in the future (Nelson et al. 2009) potentially forcing irrigators to use water containing higher levels of salt. Saline water is already used by many irrigators around the world to produce food due to limited fresh water supplies. How these farm businesses deal with saline water to grow crops gives an insight into a future with less water.

Background

In Australia, 38% of irrigated agriculture (NFF, 2011) and over 40% of Australia's total agricultural production value comes out of the Murray Darling Basin (MDB) (MDBA, 2008). The MDB is significant to this report because of the large role it plays in irrigated agriculture in Australia; 60% of the country's irrigation water is used there (CSIRO, 2008).

Climate change, water reform and population growth look set to change the future availability of water for food production. This report proposes the idea that saline water, defined as having an electrical conductivity greater than 1.5 deciSiemens per metre (dS/m) (960 parts per million), has a part to play in filling the void of future losses of surface water.

A report by the Commonwealth Science and Industries Research Organisation (CSIRO) on future water availability for the MDB predicted an 11% reduction to surface water by 2030 based on a median climate change forecast (CSIRO, 2008). Until recently, drought has affected production for nearly a decade in this area and irrigation has played a vital role in maintaining productivity. In 2009, the lowest inflows to the basins catchments (MDBA, 2009) were recorded, drastically affecting water availability and prices and giving us a glimpse of how climate change may affect irrigated agriculture.

Many who could, turned to groundwater to supplement their irrigation needs. Groundwater represents 16% of the total water used in the basin (CSIRO, 2008) and typically carries higher levels of salts than surface water. Recently, allocations to six of the major groundwater systems of New South Wales (NSW) have been reduced (NSW Office of Water, 2011).

In an endeavour to maintain productivity, faced with a future of reduced water availability, irrigators will consider the use of drainage, ground or waste water that may have previously been considered too salty. Groundwater is already widely used for irrigation. It was estimated

in 2004-05, groundwater made up over 30% of the total water used in Australia (National Water Commission, 2011). CSIRO predict groundwater use will double by 2030 and will represent more than one quarter of the total average water use in the MDB despite existing controls to reduce extractions (CSIRO, 2008). This will bring more salts into a farming system and the catchments in which they reside. How irrigators apply that water on their crops will have a major influence on future yields, soil health and the total tonnes of salt added to a catchment. The aim of this report is to investigate if saline water can be successfully used without desalination, and what practices are required to reduce the effects of it on the crops and catchments they are applied to. Additionally, this report may provide ideas to improve current groundwater use.

Results/Key findings

After many months of travel through the USA and Middle East targeting areas with saline land and water, some common themes presented themselves as answers to how saline water can be successfully used. These were:

- pressurised irrigation systems that make no contact with crop foliage, particularly for drip irrigation
- improved salt tolerance in commonly grown crops contributes to a greater flexibility in land and water quality options for irrigators
- genetic variation within crop species can be diverse, often providing improvements in salt tolerance
- research and development still remains a key element in successfully managing salinity
- combinations of good drainage, crop type and water application methods are more successful than just one element alone
- the salt tolerance of crops can be greatly enhanced by farming techniques

Often a unique example would present data or ideas that lend themselves to improving salinity management. These were:

- biological activity has demonstrated improvements in salt tolerance under saline irrigation. Further development and understanding of this could contribute to higher yields under those conditions

- conservation tillage techniques have demonstrated improvement to water infiltration, reduced evaporation and improved soil structure which are all desirable in the use of saline water
- a lack of salt tolerance ratings is not distinguishing differences between crop varieties, inhibiting a growers ability to take advantage of advances in soil mapping technologies, limiting crop, land and water use options

Recommendations

Decades of study into the use of saline water has provided a wealth of information for producers. Continuing studies will never lose their relevance given salts exist in all forms of irrigation water (Adrol, Yadav & Massoud, 1988).

The squeeze for water is on irrigators in the MDB from all sides, now and into the future. It will require new technologies and practices across many facets of agriculture to compensate for a future with reduced water availability.

It is recommended:

- future investment in irrigation will need to consider systems capable of applying fresh and saline water that minimise the impacts to crop and catchment. This will maximise opportunities to use a wider spectrum of water quality to counter reductions in surface water availability. Incentive programs and on farm demonstration days should be used to encourage wider adoption of these irrigation systems, particularly drip irrigation
- to develop higher salt tolerance in currently grown crops to allow a wider choice of land and water use
- to develop a salt tolerance rating for crop varieties. This will complement current soil surveying technologies and broaden land use options to optimise crop production
- research and development into strains of soil biology and farming practices that improve crop salt tolerance under Australian field conditions
- adoption of conservation tillage practices to offset soil degradation brought about by the use of saline water

Saline water has a role to play in maintaining productivity, maximising opportunities and building resistance to adversity.

Introduction

In 2009, water inflows in the Murray Darling Basin (MDB) hit a historical low (MDBA, 2009) reflecting the severity of the ongoing drought that stubbornly resided through south-eastern Australia for most of the last decade. High demand for water from both the community and agriculture drove water, fodder and food prices up.

The future looks set to challenge irrigators further with forecasts of increased temperatures, reductions in rainfall due to climate change (CSIRO, 2007), water reform and population growth. The ability to maintain productivity under these conditions will force irrigated agriculture to contemplate the use of other sources of water previously considered too salty.

This report stems from the authors own experiences during his 2010 Nuffield studies and the previous twenty years of growing processing tomatoes with saline groundwater.

Increasing salinity from the only water source on the property (shallow groundwater) in the last five years posed the question, can irrigating with saline water be sustained? On becoming a Nuffield Scholar in 2010, the chance to pursue this question and find some answers in countries that irrigate with saline water was undertaken.

Objectives

Australian irrigated agriculture is facing a world with less water as a consequence of climate change, water reform or population growth. It appears likely that all three will contribute to a greater reduction of its future availability.

The objective of this report is finding an answer to this and considers saline water as an alternative. There are hazards associated with this idea and with those hazards come limitations. Finding out what they are and what practices work around them may help to broaden options for irrigators in a time of need and improve on current groundwater practices.

To achieve this outcome the following questions were posed:

- can the use of saline water be sustained without the added expense of desalination?
- what application strategies work best with saline water?
- are there ways of maintaining soil health after applying saline water?
- what options are there in salt tolerant crops that can be grown commercially?

To answer these questions, tours of the Middle East and the USA began in 2010. The objective was to target field trials, researchers, agronomists and farmers in areas with a history of using saline water or farming saline soils.

Leaching requirements

Leaching requirements are based around the fact that not all plants can tolerate high levels of salt in their root zone; it is one of the major requirements in the use of saline water. Many of the crops we grow today have low salt tolerance. Those with tolerance have a variety of tactics to deal with salt. Some have the ability to exclude the uptake of sodium (Munns, 2002), accumulate salt in modified leaves (Glenn, Brown & O'Leary, 1998) or simply be able to survive on the small amount of fresh water they manage to extract from saline water. Whatever the strategy, once their threshold of tolerance has been reached the plants ability to draw fresh water from saline water diminishes and yield loss or even death can result. Extra water must be applied above the crops requirements to flush the accumulated salts from the root zone and get salinity below levels that cause significant yield loss.

Adding extra water to any crop to flush salts seems to contradict the aim of trying to conserve water. For saline irrigation to find a real future in agriculture, leaching requirements will have to be brought back to a bare minimum to limit the total volume of saline water, and therefore salt, to a field and ultimately a catchment. To achieve this, the following subjects will be covered:

- water infiltration
- drainage
- evaporation
- rotation
- drip irrigation systems
- salt tolerant crops
- nutrients
- biotechnology

Water infiltration

Soil structure is important in maintaining water infiltration and is generally regarded as one of the key elements to soil health. The most negative effect of high saline water is the destruction of the soils physical properties (Letey, 1993). In a strange twist, rainfall or the addition of fresh water through irrigation can lead to infiltration problems after the use of saline water. The presence of a high sodium adsorption ratio (SAR) in the irrigation water can be the cause of this. It is somewhat ironic that adding fresh water to reduce salinity will lead to further degradation of soil structure (figure 1). Attention to SAR is as important as the salinity of the

water or soil. Any irrigator could be lulled into a false sense of security because of low salinity levels indicated by a low Electrical Conductivity (EC). High SAR in the presence of a low EC tends to lead to infiltration problems. The same is true for soils with a high Exchangeable Sodium Percentage (ESP) (Letey, 1994). If water cannot enter the soil you cannot leach salts out of the root zone.

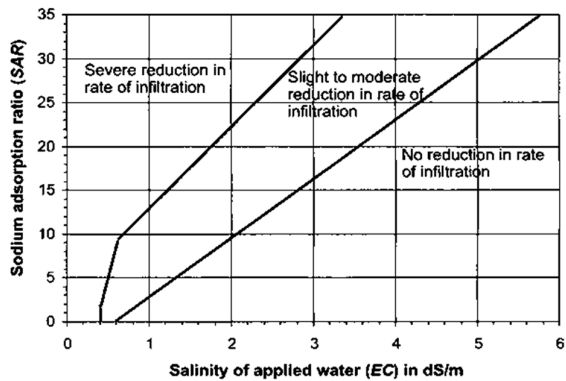


Figure 1: Water Infiltration chart (Tanji and Kielen, 2002)

The application of gypsum (calcium sulphate) is an effective way of improving infiltration rates on water with a high SAR. A number of studies have reported annual application of gypsum have allowed continual use of water with high SAR without damage to soil structure (Dudley, 2008).

Calton Duty, a tomato grower in the San Joaquin Valley, has built a low cost tank system to introduce gypsum into his irrigation water in order to reduce the SAR. Gypsum is put in to a fertiliser tank with a pressurized inlet at the base. A PVC main on the inside of the tank, across the base, has smaller pipes angling off it at 90 degrees. These offshoots have a series of small holes allowing even distribution of water across the base of the tank. Under pressure, water percolates to the surface dissolving the gypsum. An outlet at the top allows dissolved gypsum to exit the tank, retaining any solid material. This can be flushed out via another outlet at the base of the tank to be spread in the field at a later date. Carlton advised using high quality gypsum to ensure a high percentage dissolves.

One third of Australia's soils are sodic (Nova, 1999) and is relatively common throughout the MDB. Sodicity can pose a problem with infiltration before any saline water has been applied (Rengasamy, North & Smith, 2010). Once again, the use of gypsum is a common and reliable fix. When sodic subsoils exist, spreading gypsum in greater volumes is required and may take many years to alleviate this problem. Large quantities of gypsum across many hectares over

time can become an expensive burden. Ground truthing in combination with an Electro Magnetic 38hMk2 (EM38) surveying unit may have the potential to reduce this cost by half.

Electromagnetic surveying

EM surveying is a process of mapping EC in the soil profile, correlating that with a global positioning system (GPS) and cross referencing the results with soil tests. The end result is a field map marking out variation in soil type and EC. This can then be used to identify soils that may have potential infiltration problems allowing for a more targeted application of amendments prior to saline water being introduced. Several forms of EM devices were observed including hand held probes at the International Centre for Biosaline Agriculture (ICBA) in Dubai, modified tines and a custom made self-propelled testing unit developed at the United States Salinity Laboratory. Currently in Australia, an EM38 survey can be done for as little as \$7 per hectare (P.Baines, personal communication, March 2011). The EM unit is dragged across the field by a vehicle guided by a GPS and quickly covers a lot of ground accurately. This represents a quick and cost effective way to measure and respond to potential infiltration problems. Many researchers spoken to point out that very dry soil can affect readings so timing of a field survey may need to be considered for best results.

Compaction

Compaction can be a barrier to water infiltration (Qld Gov. PIF, nd). Much of the broadacre farming in Australia is focused on improving soil structure through minimising soil compaction. To address this controlled traffic farming (CTF) has been used. This basically means all vehicles and equipment that enters a given field has the same axle width and share the same tracks made in that field. All implements have a common width or are multiples of that width, restricting compaction to a set of tracks only.

CTF improves infiltration by reducing the area compacted by machinery. Unfortunately, CTF was absent in many saline irrigated fields visited.

Tillage

Minimising tillage represents a cost and time saving to producers but also contributes to organic matter and soil structure. The result from these practices contributes to an increase in infiltration (figure 2). It does this by providing protection in the form of shade, minimising evaporation and shielding the soil surface from heavy rains. The pounding of heavy rains can contribute to the breakdown of surface structure leading to crusting and poor infiltration.

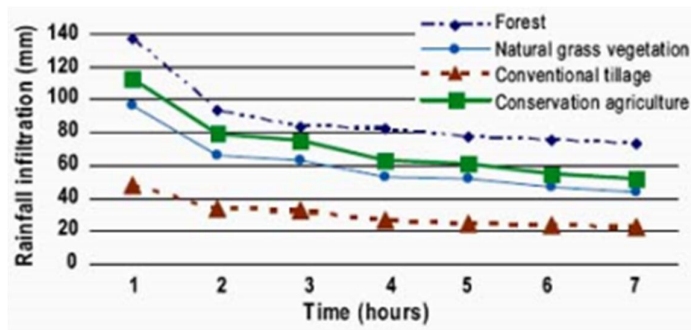


Figure 2: Water infiltration under different types of management (Bot and Benites, 2005)
Stubble retention is covered in further detail under the heading Evaporation.

Organic Matter

Organic matter plays an important role in soil health contributing to soil structure and improved water infiltration (Bot and Benites, 2005).

While in Bakersfield, California (CA), a visit to a large scale lucerne trial conducted by Blake Sanden demonstrated how highly saline soil can be brought back to production by adding large volumes of organic matter in the form of compost.

What makes the trial even more interesting is that composted biosolids were used from a nearby treatment plant. The biosolids were applied at 33.7t/ha (15t/ac) and 67.4t/ha (30t/ac), replicated on soils with an average root zone salinity of 8dS/m. Areas within the trial were over 40dS/m (nearly seawater salinity). ESPs were between 13 and 88, a potential for major infiltration problems. Under these extremes all test plots that had biosolids applied to them established lucerne faster (figure 3) and yields were significantly higher than those without. The 67.4t/ha trial yielded 17% over the control (Sanden, 2009). Infiltration was also greatly enhanced (figure 4).

The trial commenced in 2008 and upon visiting the site in 2010 it was hard to believe there was a problem with salinity at all.

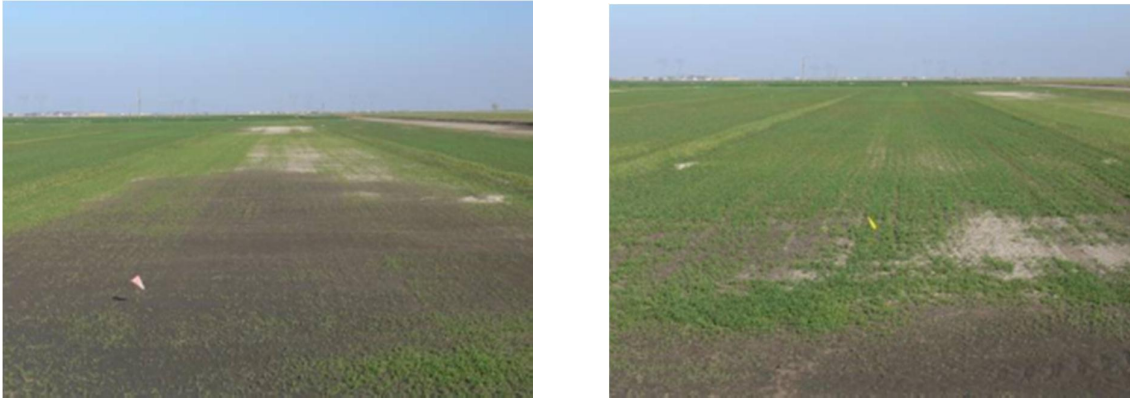


Figure 3: (Left) Control on rep. 4, March 2008. Both biosolid replications can be clearly seen either side of the control.

(Right) Biosolids at 67.4 t/ha (30t/ac), rep. 4, March 2008 (Sanden 2009)

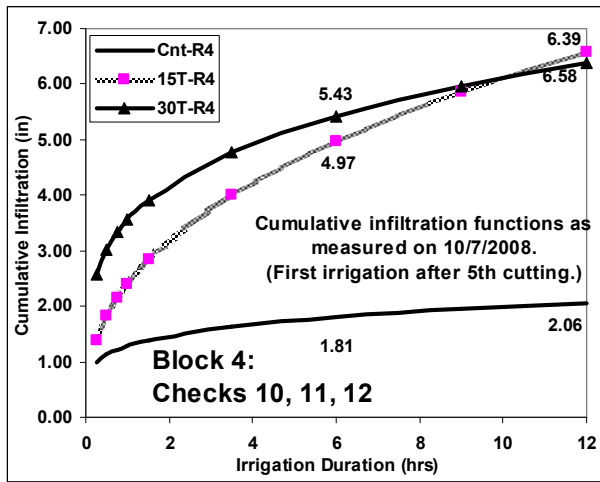


Figure 4: Infiltration rates on rep. 4 (Sanden, 2009)

Drainage

Soil type can play a big role in reducing leaching requirements through good drainage. As far back as 1949, ecologist and horticulturalist Hugo Boyko demonstrated many plants would grow beyond their normal salinity limits in sandy soils (Scientific American, 1967). Soils that tend to drain freely and have a low water holding capacity are more conducive to leaching. On many occasions in the Middle East, vegetables with low to moderate salinity tolerance were receiving saline groundwater as high as 8dS/m with no visual damage to crops. Sandy soils were observed on every site.

Sand dominant soils do not have a high water holding capacity so more frequent irrigation is required to attain commercially acceptable yields. The extra water applied to sustain moisture levels is effectively leaching salts. This may not offer any net gain in water savings.

Soils with high clay content have greater water holding capacity but this also can translate into a greater salt holding capacity. Water movement through clay is greatly reduced because of its density and may need artificial drainage placed in or below the root zone to provide adequate drainage. The Imperial Valley, CA, relies on tile drainage to keep shallow water tables and salinity under control because of the dominance of clay in many parts of the valley. Onions growing beside a salt pan with little to no visual side effects was just one of many examples of good drainage (figure 5). Often drainage is recycled and examples of farmers with systems capable of catching saline drainage water and reintroducing it to a main supply channel for reuse were common.



Figure 5: Onions beside a salt pan, Imperial Valley, CA.

(Photograph by B. Stillard, March 30, 2010)

Crops are essentially less sensitive to salt stress on light textured soils (Dudley, Ben-Gal & Lazarovitch, 2008). A balance between permeability and water holding capacity may give the greatest potential for water use efficiencies in a saline irrigated system.

Evaporation

When water evaporates salt does not. Evaporation can contribute to an increase in salt concentration. When seed is used to establish a crop the risk of salt causing poor germination or death of the seedlings can occur, particularly in areas or times of the year that have very high evaporation levels. In the Imperial Valley, offset sowing or offset bed formations were observed with flood irrigation. This is a strategy whereby the bed is formed to a peak slightly off to one side of the seed line. Evaporation is highest on the peak and salt tends to accumulate there (figure 6). Seed is placed below the peak which is effectively below the highest salt concentration.

This is not a new idea and variations on bed shape and double row setups exist. It does demonstrate how evaporation can affect soil salinity and how it can be manipulated.



Figure 6: (Left) **Corn on offset beds, Imperial Valley, CA.**

(Photograph by B. Stillard, March 30, 2010)

Figure 7: (Right) **Cotton irrigated inter-row, Tulia, TX.**

(Photograph by B. Stillard, June 30, 2010)

Overhead sprinkler irrigation was rarely seen applying saline water in the Middle East and USA. Sprinklers can concentrate salts on the crops foliage as the applied water evaporates off, leading to foliage burn and a possible reduction of yield.

Micro sprinklers in pistachio trees around Bakersfield avoided this problem by being low to the ground under the trees canopy. Bubbler heads on centre pivots irrigating cotton in Tulia, Texas (TX), also negated this issue by dropping water in between the crop rows (figure 7).

Drip irrigation systems were by far the most common irrigation system using saline water. It was prevalent through Dubai, Abu Dhabi, Jordan and Israel growing everything from vegetables to forage crops. It is commonly regarded as one of the most water efficient irrigation systems because of the minimal evaporation loss it offers. Plastic mulch was sometimes used in conjunction with a drip system for the dual purpose of weed control and minimising evaporation further. It is worth noting that plastic mulch will not allow rain to leach salts from saline soils. Hence, plastic mulch was prevalent in very low rainfall zones.

Nethouses were common in the southern half of Israel and were often used in combination with plastic mulch and drip systems to take evaporation loss to extremely low levels. Nethouses reduce wind speed and provide shade to the crops, keeping them cool.

Minimum or zero tillage or the retention of crop residue used to reduce evaporation in a saline irrigated field was absent throughout the Middle East. The lack of crop residue being used for this was largely due to high forage demands for livestock.

Conservation Tillage

The collective practice of minimum or zero tillage and the retention of crop residues to maintain ground cover are referred to as conservation tillage. In the San Joaquin Valley, CA, it is gathering popularity and groups like the Conservation Tillage and Cropping Systems Workgroup are involved in promoting its virtues. Their goals are based around fuel savings, reducing labour costs and dust suppression but their practices of minimising tillage and the resulting increase in organic matter, soil structure and ground cover results in better water infiltration and lower evaporation levels (figure 2). These are goals that reduce the impacts of saline water and could be incorporated in to a saline irrigated program.

Conservation tillage requires some specialised equipment due to the increased organic matter. An example of this for horticulture was an experimental transplanter at Five Points, CA. Jeff Mitchell (UC Davis) is a cropping systems specialist who developed a disc transplanter for establishing vegetable seedlings in heavy crop residues (figure 8). This minimises soil disturbance and maintains crop residues.



Figure 8: Direct drill transplanter, Five Points, CA (Photograph by B. Stillard, April 7, 2010)

Rotation

Rotation is usually used to control disease and pest problems in agriculture. It is a tactic to overcome limitations to production and prevent a build-up of a given problem for future crops. Introducing saline water to a field could be seen in the same light. By breaking a field irrigated with saline water and utilising natural rainfall to leach salt built up, it may be possible to get soil salinity down to low levels on returning to that field (Raine, 2007). The idea there is an advantage to allowing time and natural rainfall to bring salinity down to low levels is reinforced by experiments in cotton that have shown, if the soil profile is nonsaline

initially, yields may not be depressed during one growing season even though high salinity water is used. There may be little advantage using additional irrigation water for leaching (Letey, 1993).

The length of time between crops grown with saline water would have to be determined by annual rainfall, salinity levels and crop salt tolerance. If a salt tolerant dryland crop can be grown while the field is recovering the land would remain productive.

Most situations experienced throughout the Middle East could not do this because annual rainfall was as low as 75mm; not enough to leach salts or grow a dryland crop. A saline rotation is possible in a perennial crop if it has a good level of salt tolerance. In Kern County, CA, pistachios have been used with great success on saline soils. Long term saline irrigation trials conducted by Blake Sanden have shown pistachios to be quite tolerant of salinity and the tactical use of saline water has proven to save fresh water resources and utilise saline soils. Blake estimates saving between USD \$2000-\$10,000/ac over 20 years in his area by using saline ground water rather than the more expensive surface water. Eventually, the accumulation of salt will reduce profitable yields and strategic flushes of fresh water will be required ever 2-3 years (Sanden, 2009a).

Drip irrigation

Water placement and minimal evaporation loss are key elements to saline irrigation. The advantage a drip system has over many others is the placement of water near or in the root zone. Salts are pushed outward from the root zone, particularly in a subsurface drip irrigation system (SDI). The amount of water required to leach salts will be limited to the amount required to move salt out of that root zone not the field. This reduces the amount of salts applied to a field and subsequently, a catchment (Dudley, Ben-Gal, Lazarovitch, 2008).

The most unique thing a SDI can do is introduce air into a root zone. The injection of hydrogen peroxide or air into mainlines is known as oxygation. Trials have shown oxygation via SDI in saline soils improved lint yields in cotton by 18% and water use efficiency in both cotton and soybeans by 16% and 22% respectively (Bhattarai and Midmore, 2009).

Whilst travelling through the Middle East it became apparent that drip irrigation was also used on small, uneven sloping fields. This provides an opportunity to irrigate fields that may not have otherwise been and a potential for an increase in a grower's overall production.

Israel has a 95% adoption of drip irrigation. Subsidies as high as 90% (subject to rules) and incentive programs, have achieved water use efficiencies as high as 90% (D. Raz, personal communication, March 15, 2011). This is a great example of government, industry and

irrigators working together to preserve water. Many countries through the Middle East are looking to emulate this with some offering financial incentives (F. Karam, personal communication, February 3, 2011). Drip systems have demonstrated versatility as a highly efficient form of irrigation capable of applying water evenly over a variety of terrain and soil types. The capacity to minimise the effects of salinity puts drip irrigation in a class of its own. Unfortunately, it has a high establishment cost, ranging anywhere from AUD \$4000-\$6000 per hectare, depending on layout and economies of scale (D. Moon, personal communication, March 2011). Hence, it has been associated with high value crops capable of higher returns to the grower to pay for such a system.

For greater water savings, efficiency over a broader spectrum of irrigated crops will need to be targeted. With reductions to water availability forecast for the future, it could be argued that drip irrigation represents one of the best long term strategies for producers and the environment because of its ability to apply both saline and fresh water, reducing deep drainage and the total tonnes of salt introduced to the environment. Incentive programs to help wider adoption of drip irrigation systems should be considered to achieve this.

Salt tolerant crops

Crops with increased salt tolerance could provide more options for land and water use.

The following crops are a small collection recommended whilst in the Middle East. These salt tolerant crops demonstrate great potential but are relatively unknown to the general public in Australia and will take time before they find acceptance by consumers. Further reading about crops that are being evaluated can be found in the appendix.

Salicornia (*Salicornia bigelovli*)

Salicornia is so salt tolerant it is capable of being irrigated with seawater. Although markets do exist for this crop its use is still relatively small. Salicornia has upright fleshy stems that can be eaten raw and is sometimes referred to as sea asparagus for this reason (figure 9).

This tough little plant is capable of producing salt free seed with an edible oil content of 30%; the meal is suitable for stock feed and has high protein values over 35% (Ho and Cummins 2009).

Boeing and Honeywell UOP have taken some interest in this crop as a biofuel for future use in their aircraft engines and are currently working on a salt water farming project with the Masdar Institute in Abu Dhabi (L. Yousef, personal communication, January 24, 2011).



Figure 9: Salicornia (Photograph by B.Stillard, February 15, 2011)

Quinoa (*Chenopodium quinoa* Willd.)

Quinoa produces highly nutritional seed with a balance of all eight amino acids in greater quantities than wheat, barley and corn. Quinoa can be eaten and cooked like rice or barley and turned into breakfast cereal, bread, pasta or added to soups (Railey, nd).

ICBA have been testing 48 accessions of this plant as a salt tolerant crop on sandy soils (figure 10) and have reported that some varieties can tolerate salinity as high as 40dS/m, supported by findings from Hariadi, Marandon, Tain, Jacobsen & Shadala (2010). ICBA estimate an average water requirement of 255mm and have obtained yields of 2.6t/ha under saline irrigation in Dubai (Rao, 2010). Several years of trials in Minnesota by the University of Minnesota's Centre for Alternative Plant and Animal Products have failed to produce seed, suspecting high temperatures as the cause (Oelke, Putnam, Teynor & Oplinger, 2011). The achievement of ICBA to obtain yields under saline irrigation in Dubai's climate contradicts this and demonstrates there is enough genetic diversity within this species to warrant further investigation and development in to its use in saline environments.



Figure 10: Quinoa trial at ICBA (Photograph by N.K. Rao, 2009)

Salt tolerance in major crops

Improved salt tolerance in crops that are commonly grown and already have well established markets and acceptance are the way forward for broadening the use of saline land and water.

Many crops exist today that demonstrate good salt tolerance such as asparagus, cotton, zucchini and barley. **Salt tolerance is something that a plant builds up over centuries and to find new genes for the crops we grow today, old ones need to be collected and preserved for tomorrow.** Dr Ken Street is responsible for the collection of cereals and legumes for ICARDA (International Centre for Agriculture Research in Dry Areas) in Aleppo, Syria.

He is currently working on the FIGS (Focused Identification Germplasm Strategy) program. FIGS is based around the fact the geographical locations within a country have their own set of weather, soil types and insect pressures. Those pressures influence the plants that have grown there and those plants, given time, develop resistance to those pressures. By geo-referencing their location it will be possible to find other areas with a similar environment, broadening the collection of seed with the desired environmental resistance. Therefore, a plant breeder can receive seeds from areas with a focus on salinity, for example, instead of a core collection from a region that covers a wider range of environments. Results from the FIGS program for wheat have successfully identified salt tolerance in 21% of a collection compared with only 3% from a traditional core collection. Applying a FIGS program to seed collection will help in identifying a greater number of new salt tolerant genes.

Dr Rao at ICBA has several vegetable lines demonstrating good salt tolerance in their trials. Tomatoes are generally rated as moderately tolerant but have demonstrated great adaptability. ICBA are currently testing tomatoes and developing varieties suited to sandy soils irrigated with 20dS/m water. This exceeds the generally accepted tolerance of 2.4dS/m for tomatoes.



Figure 11: Dr Rao with ICBA's salt tolerant tomato trials

(Photograph by B.Stillard, January 16, 2011)

Accessions of squash, zucchini, eggplant, chillies, and okra have also been identified as potential salt tolerant lines and ICBA are currently building seed stocks for further evaluation. In addition, 40 accessions of sorghum were being assessed with some showing tolerance to 15dS/m irrigation water. Similar trends are seen in safflower and triticale trials there.

Agar is a gel typically used to grow bacteria and fungi for laboratory tests. Dr Rao has used agar to identify salt tolerance at germination in several crop types (figure 12). Large quantities of seed can be tested under controlled conditions in a relatively small area. Agar starts off as a liquid, making it easy to simulate various salinity levels. It is also translucent making it easier to observe root development.

Crop salt tolerance can vary during the life of a crop and identification of salt tolerance at germination is very important for seeded crops.

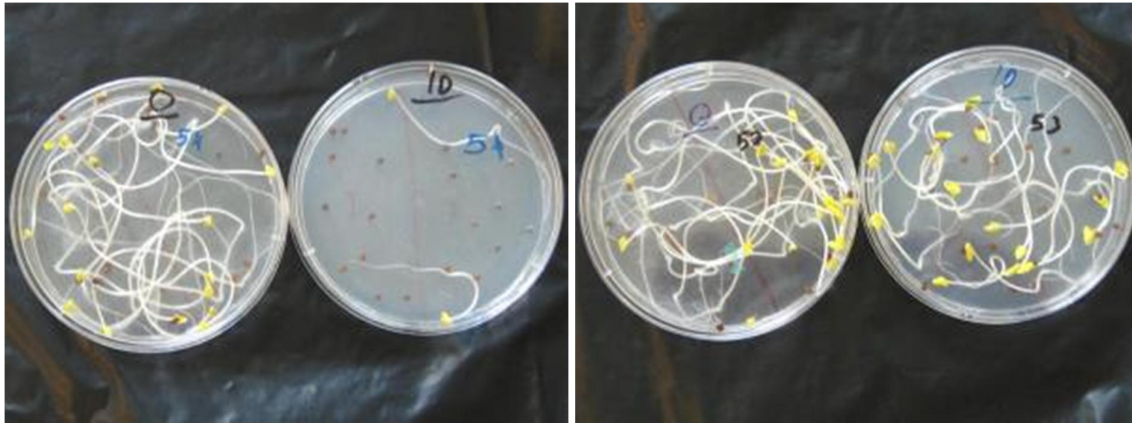


Figure 12: Salt tolerance at germination on mustard seeds (Photograph by N.K. Rao, 2008) (Left) **No tolerance at 10dS/m;** (Right) **Germination at 10dS/m**

The United States Salinity Laboratory, Riverside, were evaluating several strawberries with enhanced salt tolerance (D. Suarez, personal communication, March 24, 2010). In Jordan, the oat variety F19418-gl-a2b1c5 showed no sign of salt stress in 15dS/m soil salinity (H. Mustafa, personal communication, January 26, 2011). These examples demonstrate genetic variation exists in major crop species for salt tolerance.

Nutrients

Sodium chloride (common salt) can interfere with plant growth. By applying nutrients like potassium and calcium these affects can be minimised.

Many crops grown today do not have an off switch when it comes to sodium chloride uptake. This can result in yield loss or even death. Many crops have shown positive responses to nutrient applications in the presence of sodium. Supplementary applications of calcium have

decreased the effects of sodium chloride on the roots of maize and sorghum (Munns, 2002). In salt stress trials on barley, it has been demonstrated the addition of potassium increased dry matter, grain weight and numbers under highly saline soil (13dS/m) conditions (Endris and Mohammed, 2007). The targeted use of potassium and calcium to increase yields in crops grown under saline conditions was rarely mentioned in interviews during this study.

Biotechnology for salinity

Bacteria

Biotechnology is not new to agriculture; nitrogen fixing by rhizobia in legumes is well known and inoculation is a common practice.

David Crowley is a soil scientist based at the University of California, Riverside, and is currently working on the possible use of bacteria to help plants deal with salinity stress. He has found certain bacteria can improve plant root growth, salinity tolerance, drought tolerance and stress in general. He has been looking at applying these bacteria on avocado plants to see what effect they may have on water uptake under saline conditions. Plants suffer much faster than bacteria and fungi as salinity increases. Maintaining high soil biological activity is desirable as microbes help to maintain soil structure and includes many processes that help with plant nutrition. The main factor affecting biological activity is the input of organic matter. In most cases, there are indigenous bacteria in the soil that are able to carry out the beneficial plant microbial interactions that include hormone production (stimulates root growth), phosphorus mineralization, suppression of ethylene, and disease control (D. Crowley, personal communication, December 21, 2010). He recommended the best method to maintain biological activity under saline irrigation is to manage the soil with good leaching practices, conservation tillage with organic inputs and maintain a neutral pH.

Mycorrhizal fungi

Mycorrhizae have a symbiotic relationship with plants. Put simply, they colonise roots and convert various nutrients into a form plants can consume and in return they receive carbohydrates from the host plant. Under the right conditions, they will spread out looking to find more nutrients, virtually acting like roots themselves (Brundrett, 2008).

A trial with mycorrhizae that has shown great potential in its ability to improve salt tolerance was being investigated at ICBA (figure 13). Trials conducted with 5, 10 and 15dS/m water on palms visually showed mycorrhizae gave far greater growth responses than without, in the presence of fertilisers. These observations echoed the same trial in 2009 (ICBA, 2010).



Figure 13: Mycorrhizae trials on date palms at ICBA.

(Left) **Fertiliser only**; (Right) **Fertiliser and Mycorrhizae** (Photograph by B. Stillard, 2011)

Rhizobia

During the visit to ICBA, pulling out a volunteer legume proved to be more interesting than first thought. It was apparent the young plant was fixing nitrogen with many nodules present. This became significant when it was discovered their trial site never received nitrogen fixing bacteria and that nodulation had been observed in previous years (N.K.Rao, personal communication, January 16, 2011). It is unknown if the bacteria that has colonised the site is a local strain or not. Its ability to survive Dubai's harsh environment, sandy soils and saline water is worthy of further investigation.

These findings show encouraging signs of the positive roll biological activity plays in crop health in the presence of salinity. Further development and understanding of how these biological agents can be incorporated into saline irrigated crops and soils may add to the viable use of saline water and land in the future.

Some Surprises

A visit to the Adaptation to Climate Change in WANA (West Asia and North Africa) Marginal Environments trial site south of Amman in Jordan found Hyola 61 growing there. It was outperforming all other canola varieties in the trial. This observation cannot be considered a definitive example of Hyola 61 possessing a high level of salinity tolerance to any other, but it clearly demonstrated a higher germination rate in a soil salinity of 15dS/m (figure 14). This draws attention to the fact there is no way a grower can distinguish this

variety having higher salt tolerance over another, nor was the plant breeder aware this variety showed any significant tolerance at all (A. Easton, personal communication, April 7, 2011).



Figure 14: Hussein and Dalia Mustafa in front of Hyola 61. *In the background to the left it can clearly be seen how salinity had affected germination of other canola varieties in this trial.* (Photograph by B. Stillard, 2011)

General ratings for salt tolerance exist for many crop species but not for the varieties contained within them. It is possible that hybrid vigour was responsible for this tolerance but there is currently no way of knowing if hybrids have greater salt tolerance than conventional or if there is even variation within hybrid varieties. If this was identified by a rating system, growers may be able to make informed decisions on crop varieties for fields with a history of salinity or are intended to be irrigated with saline groundwater.

Experiences at ICBA indicate there is great genetic diversity within crop species (figure 15). The authors' own experiences in Australia growing processing tomatoes suggest differences in salt tolerance. The tomato variety Heinz 9035 has demonstrated a higher salt tolerance than Heinz 3002. There is currently no way of knowing this before planting.



Figure 15: Tomato variety salt tolerance trials at ICBA *The variety on the left is clearly outperforming the smaller plant on the right* (Photograph by B. Stillard, 2011)

Recommendations

Preparations to place agriculture in a position to successfully deal with the increased demand for food and water should be at the forefront of the minds of government, science, industry groups and irrigators. This will require financial commitment from all stakeholders.

Any investment by government, industry or growers will need to consider irrigation systems that increase water use efficiency and minimise the effects of salt allowing opportunities to use a broader range of water qualities in the future.

Salt tolerant crops should be considered for further development to widen water and land use options for growers.

Biological activity has been shown to increase crop growth under saline conditions. Farming practises that promote biological activity and the positive affect it has on plant growth, yield and salinity tolerance needs further research and development under Australian conditions.

Education programs for irrigators on salt and its interaction with crops and soil types will strengthen productivity. It will also help to minimise any impact on the environment.

Creation of an industry wide salt tolerance index for crop varieties will enhance land and water use options for growers. A lack of such a system is failing to take advantage of current soil mapping technologies and to better utilise available cultivars.

Further investigation into the benefits of oxygation on crops and soils, both in a saline and freshwater system, will shine light on its potential to increase water use efficiency and yields in a subsurface drip system.

On visiting countries that have limited water supplies it quickly becomes apparent how much prosperity irrigation brings to communities and farming families. Maintaining that prosperity with less water is going to be the single biggest challenge for irrigated agriculture in the MDB. This study has found saline water has a role to play in maintaining productivity and conserving surface water for communities and the environment. Salt and its effects on soils and crops are dynamic and diverse. Farming systems need to share these traits to successfully utilise saline water.

Appendices

Salt tolerant crops continued

Sea aster [*Aster tripolium* L.]

Typically seen growing in salt marshes, sea aster is a native of northern Europe. Sea aster shares some well-known cousins like chicory and lettuce. Studies into the possibility of using this plant as a salad were underway at the Ramat Negev Desert Research Station in Israel. Sea asters performance under saline irrigation up to 10dS/m is being evaluated. Visually there was little difference in growth in all salinity trials at the research station.

Portulaca [*Portulaca oleracea*]

Portulaca has a long history in agriculture with records of this dating as far back to the 4th Century BC (Science Web, n.d). Portulaca has some of the highest levels of omega 3 of any leafy vegetable (Zion Shemer, personal communication, February 15, 2011) and although considered a weed in many countries, its ability to weather drought and salinity may bring it back in to favour. Portulaca can be eaten raw in salads, cooked or steamed. At the Ramat Negev Desert Research Centre trials with the use of saline water were being conducted to evaluate yield under a range of salinities as high as 10dS/m. The research centre is currently studying sea aster and portulaca for future use as a salad mix.

Guar [*Cyamopsis tetragonoloba* (L.) Taub.]

More commonly known as cluster bean, guar is a drought tolerant legume suited to sandy type soils in arid and semi-arid regions. It is commonly grown in India which currently supplies 80% of the world markets. It has shown no adverse response to irrigation water between 8-10dS/m in trials at ICBA, yields of 2.5t/ha are comparable to crops grown in nonsaline conditions. Dry matter yields have been recorded as high as 12.8t/ha and is estimated to require 350mm of water (Rao, 2010). The value of guar is in the gum that is extracted from the endosperm inside the seed. The gum is used as a thickener by a diverse range of industries including food, cosmetic and mining. Examples of products that contain guar gum in the food industry are ice cream, tomato sauce, cheese and noodles; cosmetic products containing guar gum are shampoo and toothpaste; guar gum in mining products for fracturing fluids and explosives gel. Guar has been grown in Australia and a review of further advancement to the industry was published as late as 2004 (Bryceson and Cover, 2004). Attempts to establish an industry have not come to fruition despite the crop being grown in Australia since 1910. In

West Texas, however, a small industry has successfully established, sown and harvested with conventional machinery (Latzke, 2008). Guar seed meal has been recorded having protein levels over 30% making it a valuable stock feed grain (Undersander et al., 2011). Recent reports have priced guar at USD \$2000/t (Prolonged Guar Gum price, 2011). Guar's combination of salt tolerance, feed quality and uses in several industries represent a wide range of market options. There are no registered weed control chemicals in Australia for guar and this may prove to be a major problem. At the very least, guar represents a potential salt tolerant feed and forage grain legume that would be a valuable addition to any rotation.

These crops represent potential in a saline environment but they will take time to develop market volume.

Desalination

Though this study sets out to find ways of using saline water without the added cost of desalination, it would be remiss not to include some observations on the matter. By far the most common desalination system seen was reverse osmosis (RO). RO systems require high operating pressures; systems looked at in Israel were running at 18 bar. This requires a lot of energy and running costs there were around AUD \$400/ML, depending on the salt load (U. Na'amati, personal communication, February 15, 2011).

Desalination removes all forms of salt from an irrigation supply, including beneficial salts like potassium and micro elements which may need to be replaced with commercial fertilisers. Growers in Israel reported unusual nutrient deficiencies when too much salt was removed from their water supplies (E. Tripler, personal communication, February 16, 2011).

Physically, desalination will remove salt from water but that salt still exists in a separate line as a brine solution and safe disposal of this brine is a major consideration. John Diener, based in California, is working with researchers on a system that distills this salty brine into a concentrated solution and through a chilling process drops out the various elements contained in that brine. The elements like boron, selenium and calcium can then be sold as high grade minerals offsetting the cost of desalination. The distilling process returns 5 to 10% of the original fresh water lost in the brine increasing the recovery of fresh water from 80% to 90%. John was waiting on the final piece of the puzzle, a cathode anode set up developed at the Colorado School of Mines. It draws the calcium and magnesium out of the water before it enters the RO system. This reduces its running cost dramatically because calcium and magnesium are the major elements that block RO filters there (J.Diener, personal communication, April 7, 2010).

As RO systems become cheaper they will become more common. If systems come with the type of technology that allows the separation of salts into a saleable product, desalination may make saline water a valuable commodity.

Nuffield Australia's Global Focus Program (GFP)

An Australian Nuffield Farming Scholarship has a unique program at its core. It puts not only Australian scholars, but many other scholars from Nuffield's stable of countries together on what may best be described as a whirlwind tour of global proportions. Typically, small groups set off to see agriculture from all around the world. You may be in Texas one day and Inner Mongolia the next. The value of this is only truly realised when you have time to look back. The friendships made and experiences had are once in a lifetime. To my GFP group, Desiree Reid, Ben Hooper, Alan Redfern, Paul McGill, Ben Tyley, Helen Thomas and Ed Cox, I thank you for making this experience a great one. The individual skills, knowledge and enthusiasm for agriculture that each of these people brought to our trip was outstanding and added to the experience.

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Plain English Compendium Summary

Project Title:	Irrigation with saline water Can it add value to agriculture?
Nuffield Australia Project No.:	1009
Scholar:	Brad Stillard
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Objectives	To discover if saline water can add value to agriculture; what practices can sustain its use as a viable alternative to fresh water without the added cost of desalination.
Background	The decade long drought that affected production and water allocations in the MDB throughout 2000-2010 placed considerable pressure on farmers, water supplies, communities and the environment. CSIRO made predictions that climate change was set to reduce water availability in the future and the MDB plan was put forward to return water to the environment through the acquisition of water rights, thus, further reducing water availability. Rising salinity in the authors own groundwater supply prompted the question whether this can be sustained and, if so, can the use of saline water help maintain irrigators productivity in a future with less water to grow food?
Research	Five months of travel in five continents, particularly the USA and Middle East, throughout 2010-11. Interviews with farmers, agronomists and scientists combined with visits to research stations and trial sites provided the foundations of this report. This was backed up with reviews of research papers in the field of salinity and the use of saline water for irrigation.
Outcomes	The use of saline water can add value to agriculture by allowing production of food to continue when freshwater supplies are limited. Irrigation methods and systems, crop salt tolerance, soil type and health all play an important role in its use.
Implications	Saline water has its hazards and so there are limits to its use. These hazards can be reduced. Many of the tools required to achieve this are out there but it will take financial commitment from government, industry and irrigators to see them put into action. It is important that research and development continue to reduce the hazards of saline water so irrigated agriculture can maintain production and increase land and water use options. This will give irrigators the tools to cope in a future with reduced water availability.
Publications	Nuffield Australia