Impact on soil hydraulic properties resulting from irrigating saline-sodic soils with low salinity water.

Matthew Bethune
Department of Natural Resources and Environment, Private Bag 1, Ferguson Road, Tatura, Victoria.

Background.

Irrigated pastures occupy 0.7 million hectares of land in Australia. Much of this area has developed high watertables and requires implementation of salinity mitigation measures. Groundwater pumping and its subsequent reuse for irrigation is a key salinity control measure in salinity management plans of the Murray Darling Basin, Australia (Prendergast, 1993). The reuse of highly saline-sodic groundwater leads to accumulation of sodium in the soil profile and can result in sodic soils. Characteristic to sodic soils is poor soil structure (Rengasamy and Olsson, 1991), resulting from the swelling and closure of inter-aggregate pores and the dispersion of fine particles that clog the soil pores. This reduces soil permeability to water and air, causing poor aeration of the rootzone, waterlogging, reduced water movement in the rootzone and restricted root growth (van Hoorn and van Alphen, 1994). Infiltration of irrigation water may also be limited, leading to plant water stress and reduced pasture dry matter production.

The exchangeable sodium percentage (ESP), electrical conductivity (EC) and pH of 1:5 soil water suspensions are key indicators of soil sodicity related structural decline (Rengasamy and Olsson, 1991). The risk of soil structural decline will be greatest when soil ESP is high and EC falls below a threshold EC (TEC). Leaching of soluble salts from a saline-sodic soil by rainfall and irrigation with low salinity water will result in degraded soil structure (Rengasamy and Olsson, 1991). Laboratory studies have shown reductions in soil permeability as a result of leaching saline sodic soils (Minhas and Sharma, 1986). However, field studies need to be conducted to examine whether laboratory results apply to field conditions.

Two situations that are commonly encountered under field conditions that could lead to low soil EC and high ESP and therefore reductions in permeability. Firstly, winter rainfall periods in combination with long term groundwater reuse. Groundwater reuse over the summer period will increase both soil EC and ESP. Winter leaching by low salinity rainfall could reduce soil EC to a level where soil dispersion occurs. Groundwater reuse will not be sustainable if this winter leaching has long term impacts on soil hydraulic properties. The second situation occurs when groundwater reuse is stopped after a number of years of saline irrigation. Leaching with low salinity water in combination with rainfall could reduce soil EC and potentially lead to sodicity related structural decline. This will be most likely a problem in the future when groundwater salinity becomes too saline for reuse or there is a change in crop.

This experiment examines the change in field measured soil permeability and infiltration caused by irrigating highly saline-sodic soils with low salinity irrigation water. The experiment is limited to in-field hydrologic impacts of a flood irrigated red brown earth with established perennial pasture.

Materials and Methods

Site description

The experiment was conducted at the Institute for Sustainable Agriculture at Tatura (36^o 26’ S, 145^o 16’ , altitude 114 m) in the Shepparton region of the Murray Darling Basin, Australia. The soil is classified as Lemnos Loam (Skene and Poultsma, 1962) or Natrix Zeralf (Soil Management Support Service, 1983). It consists of 0.15 m of loam at the soil surface overlying a heavy clay B horizon extending to a depth of 0.7 m (Table 1).

Table 1. Physical properties of Lemnos loam at the experimental site (After Prendergast et al, 1993) ρ_b= bulk density

Depth (m)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	ρ_b (Mg/m3)
0.1	7	30	31	29	1.5
0.2	4	29	29	38	1.7
0.6	1	18	24	56	1.7
1.1	1	24	24	50	1.7
1.4	1	23	22	54	1.6

The experimental layout consisted of 12 plots, each of area 75 m^2. A plastic skirt was installed to 0.5 m depth around the perimeter of each plot to prevent lateral water movement. A groundwater pump installed at the site extracts groundwater of salinity 4.8 dS/m from an aquifer 10 m below the surface.

Perennial pasture was established at the experimental site in 1987. The pasture consisted of perennial ryegrass (*Lolium perenne*), paspalum (Paspalum dilitatum), white clover (*Trifolium repens*) and strawberry clover (*Trifolium fragiferum*).

Irrigation
Two periods of irrigation with different salinity water were monitored in this experiment. The first period involved irrigating with three levels of saline water from October 1987 to March 1997. The second period involved irrigating all plots with low salinity irrigation water from April 1997 to April 1998. Experimental treatments and salinity of irrigation water for each period are summarised in Table 2. There were four replicates for each treatment. The chemical composition of the irrigation waters are given in Table 3. Hydraulic properties were measured intensively between October 1995 and May 1998.

Table 2. Salinity of irrigation for the two irrigation management periods.

Treatment	Irrigation with saline water October 1987 to March 1997	Irrigation with fresh water April 1997 to April 1998.
T1	0.1	0.1
T2	2.5	0.1
T3	4.5	0.1

Table 3. Chemical composition of irrigation salinity levels.

Irrigation water salinity dS/m	Na $mmolcL^{-1}$	K $mmolcL^{-1}$	Ca $mmolcL^{-1}$	Mg $mmolcL^{-1}$	SAR %	pH
0.1	.65	0.06	0.19	0.22	1.4	7.3
2.5	22	0.25	0.42	5.8	12.7	7.5
4.5	40	0.4	0.6	10.3	17	7.6

Irrigation scheduling
Irrigation was scheduled when cumulative pan evaporation minus rainfall (E-R) exceeded 50 mm. Total irrigation water applied to the plots was measured using calibrated steel drums that supplied water to the plots at a constant rate of 5 l/min, over a 90 minute period. Applied water was allowed to infiltrate for 6 hours. The remaining surface water was pumped off and measured using a flow meter.

Infiltration by volume balance
The total depth of infiltration was calculated from the difference between the depth of irrigation water applied and the remaining surface water pumped off after six hours of ponding. Infiltration by volume balance (Z_{vb}) was calculated by dividing the total depth of infiltration by the time that water was ponded on the plot surface. Z_{vb} integrates the effect of both initial infiltration through cracks and steady state infiltration through the soil matrix. Infiltration through cracks accounts for 60 -70 % of total infiltration at this site (Austin and Prendergast, 1997). Therefore, changes in Z_{vb} will most result from changes in crack formation.

Steady state infiltration rate
The steady state infiltration rate (Z_{ss}) was measured using the falling head method. Capacitance probes recorded the depth of ponded surface water on the plot during the irrigation event. The rate of fall of the ponded surface equals the infiltration rate at any time. Z_{ss} was assumed to equal the mean infiltration rate for the hour prior to removal of surface water. No adjustment in the calculation of Z_{ss} was made for surface evaporation of water. The absolute value of Z_{ss} is over-estimated by ignoring evaporation. However, evaporation will not affect the differences between treatments in Z_{ss}. Steady state infiltration reflects hydraulic properties of the soil matrix. Changes in soil matrix hydraulic properties should be relfected by changes in steady state infiltration.

Rate of change in watertable depth (ΔW)
Implications on sub-soil permeability were assessed by comparing the rate of drop in watertable (ΔW) following an irrigation event. A perched water-table forms after irrigation as the sub-soil (> 0.3 m depth) permeability is less than the topsoil (< 0.3 m). The rate that this perched watertable drops after an irrigation event is related to plant water extraction and drainage of water through the sub-soil. Pasture water use is low at night and therefore ΔW is considered to result from drainage of water stored in the topsoil of the profile into the sub-soil. This drainage is limited by sub-soil permeability and the drainable porosity in the topsoil. Poorly structured soils will have lower drainable porosity and therefore greater changes in watertable level per unit drainage compared to a well structured soil. Fresh water irrigation on sodic soils is expected to break down soil structure, reducing both sub-soil permeability and drainable porosity of the

topsoil of the profile. The combined impact of changes in sub-soil permeability and drainage porosity in the topsoil are investigated by analysing ΔW.

Following irrigation, the depth to the perched watertable was continually recorded using capacitance depth probes. The level was measured in a shallow piezometer screened between 0.4 to 0.5 m below the surface. Data between 8:00 pm and 8:00 am were used in the analysis to minimise impacts of plant water use on changes in watertable depth. The perched watertable was typically within 0.1 m of the surface during the measurement period.

Soil sampling and chemical methods
Soil samples were taken on 30/8/1995, 21/11/1996, 21/3/1997, 24/4/1997, 1/10/1997 and 30/4/1998. Samples were taken to 0.9 m depth, and divided into sub samples (0 to 0.15, 0.15 to 0.3, 0.3 to 0.6 and 0.6 to 0.9 m depths). Soil salinity was measured in a 1:5 solution (EC) and exchangeable cations were measured to calculated the exchangeable sodium percentage (ESP) in the soil. Soil samples were also collected between October 1989 and October 1991. Soil sodicity was measured using a range of measures during this period, including the sodium absorption ratio measured in a 1:5 solution ($SAR_{1:5}$) and saturation extract (SAR_{SE}). Empirical relationships between ESP, $SAR_{1:5}$ and SAR_{SE} were determined from soil samples collected in April 1998. Measurements prior to 1995 were converted to an equivalent ESP using these empirical equations. No measurements of soil sodicity were taken between October 1991 and October 1995. For reporting purposes, soil EC and ESP are presented for the topsoil (0 to 0.3m) and subsoil (0.3-0.6m).

Statistical methods.
All statistical analysis was undertaken using Genstat 5 (Lawes Agricultural Trust, Rothamstead Experimental Station). Time trends in the data sets of ESP, EC, Z_{vb}, Z_{ss} and ΔW were investigated by fitting a linear model of time through each of the data sets. The slope of this model indicates linear changes in the data set over time. Complete seasons of data were used in fitting the linear model of time to minimise the impact of seasonality on this slope, the start and end points of the linear model being at the same time of season. Treatment contrasts on the time trend were tested using analysis of variance, with the slope of the linear model being the variate. There was 4 replicates of each treatment. Regression analysis was used to assess the impact of soil and water chemistry on changes in Z_{vb}, Z_{ss} and ΔW.

Treatment contrasts on the mean Z_{vb}, Z_{ss} and ΔW during the periods of saline and fresh irrigation were analysed using the method of residual maximum likelihood (REML).

Results.

Soil chemistry
There was considerable seasonal variability in both soil EC and ESP observed between October 1989 and October, 1991 (Fig 1 and 2). Soil sampling was not frequent enough to capture seasonal changes in chemistry from March 1991 to March 1997. This seasonality makes it difficult to assess trends in soil chemistry over time. From October 1989 to October 1991, increased irrigation water salinity resulted in greater rates of buildup in ESP (Fig 1) and EC (Fig 2) in the soil profile ($p < 0.001$). Summary statistics are presented in Table 4. The period between April 1991 and April 1997 saw no further increases in soil EC or ESP with time ($p<0.001$). This indicates that both soil EC and ESP had reached an equilibrium with irrigation water salinity. Further increases in ESP and EC would only be expected if irrigation water salinity increased or leaching was restricted. Application of fresh water from April 1997 to April 1998 saw a reduction in EC and ESP in the topsoil for T_2 and T_3 treatments. There was no difference in the rate of drop over time in EC or ESP between T_2 and T_3 at these depths. EC and ESP of T_2 and T_3 were the same at the end of the trial, but still higher than T_1.

Table 4. Treatment contrasts on the linear trends in soil EC (EC_{lin}) and ESP(ESP_{lin}) with time. ns = no significant contrasts.

	EC_{lin}				ESP_{lin}			
	topsoil		subsoil		topsoil		subsoil	
Time Period	contrast	p	contrast	p	contrast	p	contrast	p
Oct-89 to Oct-91	T1<T2<T3	<0.001	T1<T2<T3	<0.001	T1<T2<T3	<0.001	T1<T2 or T3	<0.001
Mar 91 to Mar 97	ns	0.74	T1<T2 or T3	0.06	T1<T2 or T3	0.002	T1<T2<T3	<0.001
Apr 97 to Apr 98	T1<T2 or T3	0.01	ns	0.17	T1>T2 or T3	0.014	ns	0.76

High ESP and low EC are the conditions under which sodicity related structural decline is expected. There was a strong relationship between ESP and EC during both the saline irrigation and fresh irrigation periods. The slope of the linear relationship between ESP and EC reduced (p=0.05) in the topsoil as a result of fresh water irrigation (Fig 3). A 22 % change in slope was observed

Thirteen months of leaching with low salinity irrigation water and winter rainfall did not reduce sub-soil EC or ESP (Fig 1 & 2). Therefore, no changes in sub-soil permeability would be expected resulting from sodicity related structural decline of the sub-soil. The time required to reduce sub-soil salinity to the TEC is unlikely to be encountered in farming systems where consistent groundwater reuse for irrigation is practiced. Therefore, declines in sub-soil permeability under consistent groundwater reuse on pasture would not be expected. Leaching of the sub-soil may be achieved if there is a long term change in farm management, such as permanently ceasing irrigation with groundwater. Over time sub-soil EC may then drop and resulting declines in sub-soil permeability may be realised.

Infiltration rate by volume balance

There was considerable seasonal variation in Z_{vb} during the period of saline irrigation (Fig 4). However, Z_{vb} of T_2 and T_3 was on average greater ($p<0.01$) than for T_1 throughout the period of saline irrigation (Fig 4a). This result indicates that winter and summer rainfall events had no lasting impacts on Z_{vb} during the period of saline irrigation. There was no treatment effects on Z_{vb} during the period of low salinity irrigation ($p=0.76$). This is clearly seen by displaying the standardised infiltration, obtained by dividing mean Z_{vb} of T_2 and T_3 by T_1 (Fig 4b). Standardised Z_{vb} of T_2 and T_3 is greater than 1 during the saline irrigation period, while there is little difference during the fresh water period.

Z_{vb} is influenced largely by initial rapid infiltration which accounts for 70% of the total depth of infiltration (Austin and Prendergast, 1997). This rapid infiltration occurs through soil cracks and macropores. The soil shrinks upon drying, resulting in the formation of cracks (Austin and Prendergast, 1997). Sodic soils swell and shrink more than non-sodic soils. Therefore, sodic soils are likely to have greater crack development than non sodic soils. This would result in greater infiltration rates of water when irrigation is applied to dry soils by flood. Crack formation is also closely related to the soil moisture status. Greater plant water use would dry the soil and result in greater crack development. During the period of saline irrigation plant water use would be limited by high soil EC. This would reduce crack development and therefore tend to reduce Z_{vb}. These two processes, increased swelling due to sodicity and reduced plant water use due to salt stress, have opposing affects on crack developed, and therefore, Z_{vb}.

No treatment differences in Z_{vb} were observed during the period of low salinity irrigation. During this period soil salinity is being lowered and plant water use would be expected to increase. Increased plant water use would lead to greater crack development and increased Z_{vb}. Increased crack development may also result from increased swelling and shrinking caused by leaching of the sodic soils. Both these processes would imply an increase in Z_{vb} for T_2 and T_3. It is thought that any increase in infiltration through cracks during the period of fresh irrigation may have been offset by a reduction in infiltration into the soil matrix.

Steady state infiltration rate Z_{ss}.

Saline irrigation period

Irrigation water salinity did not affect Z_{ss} during the period of saline irrigation ($p=0.27$). Mean Z_{ss} for all plots during this period was 4.0 mm/hr. No significant relationships were identified between Z_{ss} and soil EC or ESP. Eight winter leaching periods which occurred during the period of saline irrigation were insufficient to cause any treatment effects on Z_{ss}. This indicates that winter rainfall and leaching on its own is insufficient to cause long term sodicity related structural decline and that long term consistent reuse of groundwater should not adversely impact on steady state infiltration.

Fresh irrigation period

A negative linear association between Z_{ss} and previous irrigation salinity (Fig 4) occurred as a consequence of low salinity irrigation ($p=0.005$). This reduction in Z_{ss} of T_2 and T_3 relative to T_1 indicates that soil structure has declined during this period. There is negative linear relationship ($p=0.02$) between ESP and the percentage change in Z_{ss} as a result of switching from saline to low salinity irrigation water (5b). A negative linear relationship also existed between increasing EC and percentage change in Z_{ss}. However, high soil EC increases soil hydraulic properties (Oosterbaan and Nijland, 1994). Therefore, it is considered that the relationship between the decrease in Z_{ss} and increasing EC arises from the strong correlation between EC and ESP (Fig 3). Further reductions in soil EC of T_2 and T_3 are likely to result from leaching as EC of these treatments had not reduced to the level of T1. Therefore, further decreases in steady state infiltration may result.

Rate of change in depth to watertable over time (ΔW)

During the period of saline irrigation, ΔW increased linearly with the salinity of irrigation water ($p<0.001$). ΔW of T_2 (6.6 mm/d) and T_3 (7 mm/d) was greater than T_1 (4 mm/d). The winter leaching events from 1987 to March 1997 have therefore not resulted in long term sodicity related declines in sub-soil permeability. The slope of a linear model of ΔW over time was not affected by salinity during the period of saline irrigation ($p=0.7$) indicating that there is no long term trend in soil permeability. The application of low salinity water from March 1997 resulted in a negative linear trend in ΔW of T_2 and T_3 with time. The rate of decline in ΔW with time was linearly related to the salinity of irrigation water during the period of saline irrigation ($p=0.01$). The percentage change in ΔW resulting from irrigating with low salinity water negatively related to sub-soil ESP ($p<0.001$, $r^2=0.7$) (Fig 6). There were no treatment effects on ΔW by the end of the trial ($p=0.9$).

The measure of sub-soil permeability in this experiment was the rate of change in a shallow watertable that perched on the sub-soil following irrigation. ΔW was affected by the drainable porosity of the topsoil and sub-soil permeability. Changes in topsoil structure were inferred from observed reductions in Z_{ss} for T_2 and T_3. No reduction in subsoil salinity was observed (Fig 1b) and therefore reductions in subsoil permeability would not be expected. Therefore, it is considered that the observed reduction in ΔW over time resulted from reduced drainable porosity in the topsoil.

Further leaching may reduce sub-soil salinity to the threshold electrolyte concentration and then result in declines in soil permeability. However, 14 months of leaching were insufficient to reduce sub soil salinity (Fig 1b). Therefore, under long term consistent groundwater reuse where salt is applied each irrigation season, sub-soil salinity is unlikely to reduce to levels where soil dispersion and reduced soil permeability become a problem. Sub-soil salinity is only likely to reduce substantially when there is a permanent change in farming enterprise or groundwater reuse is permanently stopped. Fourteen months of leaching with low salinity water, including a winter of rainfall leaching, were insufficient to reduce sub soil permeability of treatments with groundwater reuse to levels below the treatment that did not receive groundwater reuse. This indicates that sodicity related declines in sub-soil permeability are unlikely under consistent long term groundwater reuse. Extensive periods of leaching is required before problems are likely to occur.

Discussion

Winter rainfall in combination with low potential plant water use results in long periods when the soil is close to saturation. These periods create the greatest opportunity for leaching salts, especially because of the low salinity of rainfall. Low soil EC and high ESP are the conditions under which sodicity related structural decline are expected. Reductions in soil permeability have been observed by creating these conditions in the laboratory (Minhas and Sharma, 1986). In our experiment there were 11 winters of leaching and 12 summers of saline irrigation. Soil hydraulic properties were higher than on average for the plots receiving saline irrigation water over this period. This indicates that winter leaching did not have any observable long term impacts on soil hydraulic properties. There is some seasonal variation in the measured hydraulic properties that may result from short term impacts of sodicity on soil structure. However, these impacts were only short term and do not appear to be a risk to the sustainability of irrigation with saline waters.

The impact of reduced soil hydraulic properties would be decreased infiltration, increased surface ponding, poor soil drainage and reduced soil strength. This experiment has shown that consistent long term groundwater reuse is unlikely to result in decreases in infiltration. This is partially because infiltration into the studied soils is dominated by crack flow. One problem that may arise is restricted infiltration through the crack wall into the soil matrix in sodic soils. This may result in greater infiltration of irrigation water into the sodic soils through cracks, but poor redistribution of water within the soil matrix. The impact of sodicity on the uniformity of redistribution of water was not measured in this experiment.

Rainfall may occur when the soil is saturated and cracks are closed, especially in the winter period. Reduced infiltration into the matrix of this rainfall may occur in sodic soils. This would result in increased surface ponding. Laser leveling of flood irrigated pastures is recommended in the irrigation areas of the southern Murray Darling Basin. This allows quick surface drainage and prevents water ponding on the surface for long periods of time. Reduced infiltration into saturated sodic soils may actually provide some benefit in that it reduces accessions to groundwater.
Rainfall may also lead to surface sealing of a sodic soil which would restrict infiltration and winter leaching. This would be a problem in areas that depend upon winter leaching to maintain salinity at acceptable levels in the rootzone. However, this may also be a benefit for sodic soils in that it will prevent leaching of soil salinity at depth. This would reduce sodicity related structural decline at depths which are more difficult to remediate than structural problems near the soil surface.

Poor soil drainage could create problems of waterlogging, and greater soil compaction caused by animal grazing. The impact of waterlogging on pasture production is inconclusive (Ref). Flood irrigation will saturate the top part of the soil profile whether the soil is sodic or non-sodic. The drainage rate from the heavy soils typical to the study area are low and the dominate process in drying the soil profile is plant water use in summer. Therefore, it is unlikely that soil sodicity will increase the period of soil saturation during summer as a result of reduced hydraulic properties. This may not be the case in winter where plant water use is limited

Reduced trafficability and increasing cattle pugging could result in significant reduction in pasture production (NZ refer). The reduced soil strength of sodic soils near saturation may lead to greater mechanical damage induced by cattle grazing than non sodic soils. This has potential to cause long term soil structural damage which could affect pasture growth. The current experiment was not grazed, therefore the impact of grazing on saturated sodic soils was not assessed. This paper focuses solely on soil hydraulic properties of a flood irrigated red brown earth with established perennial pasture. Sodicity has other impacts on production and the environment (Refs). Such factors need to be considered in addition to the impact on hydraulic properties that are discussed in this paper.

Increased pressure on farmers to use water more efficiently may lead to a change in irrigation technique. Alternatives to flood irrigation include sprinklers or sub-surface drip. These two techniques apply water at lower rates to match infiltration characteristics of the soil matrix. For these irrigation technologies, infiltration processes will be dominated by matrix flow rather than through cracks. Sodicity reduced hydraulic properties pose a greater threat to production in this situation where it may not be possible to supply sufficient water to the plant through the soil matrix.

All treatments in this experiment developed elevated levels of soil sodicity, including a treatment that was solely irrigated with low salinity irrigation water. This indicates that irrigation of pasture in general is likely to lead to sodification of soils typical to the Murray Darling Basin. This is particularly the case in areas underlain by shallow watertable that restrict leaching. Groundwater reuse in these areas may actually improve soil structure and increase leaching. It would appear that sodification of soils growing irrigated pasture may be inevitable. Increasing irrigation water salinity simply increases the rate that sodium builds up in the profile. Management practices need to be developed to minimise the impact of soil sodicity. These practices should focus on times when there is a change in farming enterprise or groundwater reuse is permanently ceased.

Conclusion

Soil salinity and sodicity increased as a result of saline irrigation but appeared to have reached a steady state after 13 years of saline irrigation. Soil hydraulic properties were found to increase with applied water salinity during the period of saline irrigation. Winter rainfall periods during the 13 years of saline irrigation had no long lasting impact on soil hydraulic properties. Leaching of the saline sodic soils by irrigation with low salinity water and winter rainfall reduced soil EC and ESP in the top 0.3 m of the profile. There was no change in subsoil EC or ESP. Steady state infiltration was adversely affected by leaching the saline sodic soils. The decline in steady state infiltration was negatively correlated to ESP. Soil permeability and total infiltration rate were not adversely affected by leaching the saline sodic soils. However, upon further leaching it is likely that adverse impacts would be observed.

From this experiment it is considered that long term consistent farm reuse of groundwater for irrigating pasture will not adversely impact on soil hydraulic properties. However, when groundwater irrigation is ceased on saline sodic soils, hydraulic properties are likely to be adversely affected. It is important to note that this experiment was conducted under ‘not trafficked’ conditions. The impact of cattle and other mechanical impacts on the measured hydraulic properties is unclear.

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Skene and Poultsma, 1962) or Natrix Zeralf (Soil Management Support Service, 1983).

Minhas and Sharma, 1986

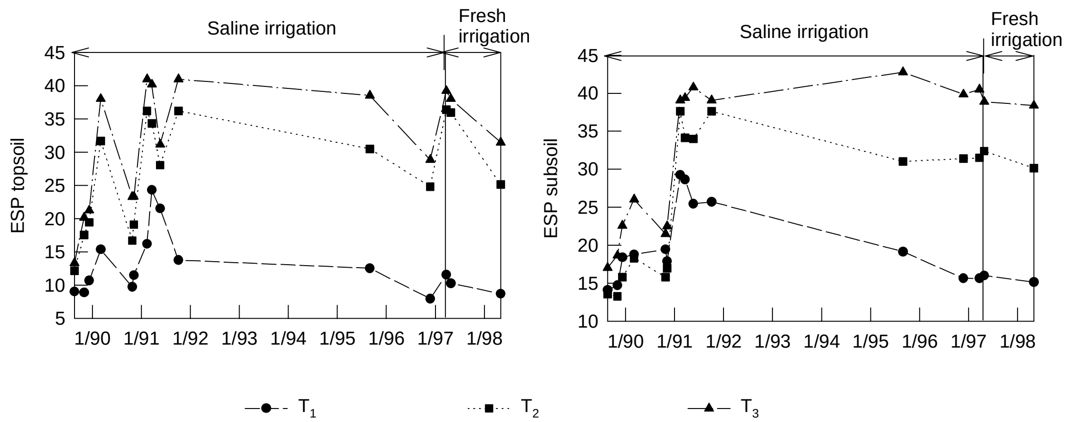


Fig 1. Mean soil ESP over trial for each treatment.

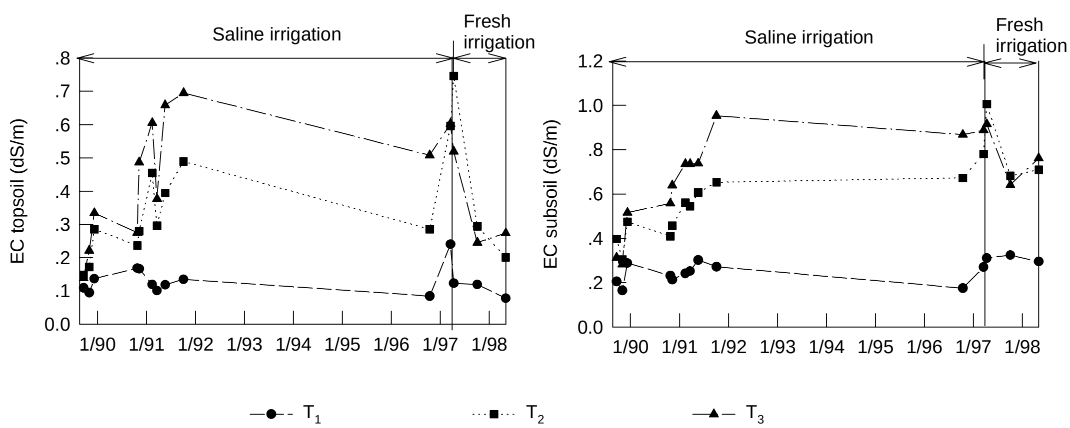


Fig 2. Mean soil salinity over trial for each treatment.

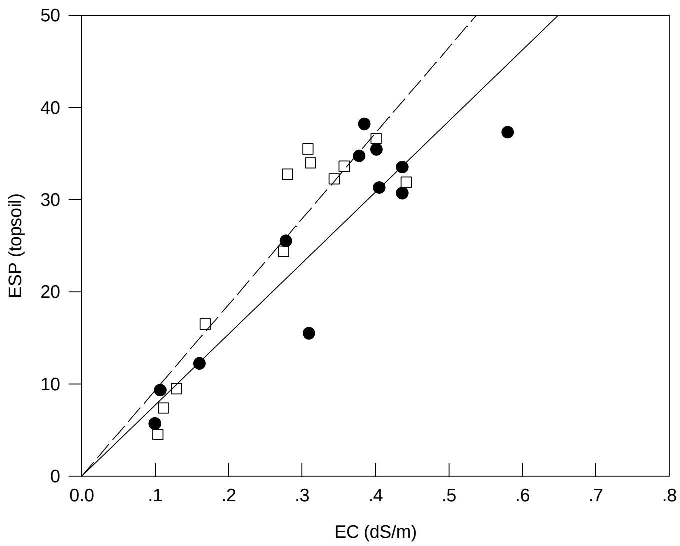
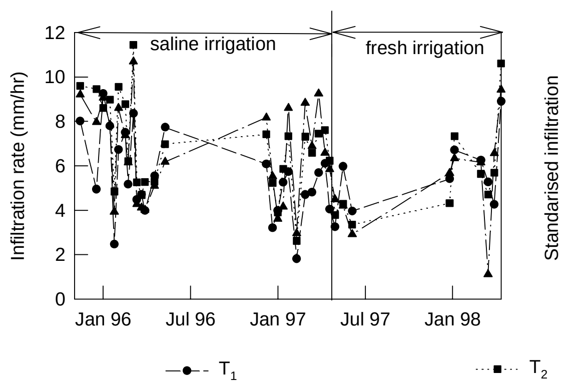


Fig 3. Relationship between EC and ESP in the topsoil prior and post application of fresh water.



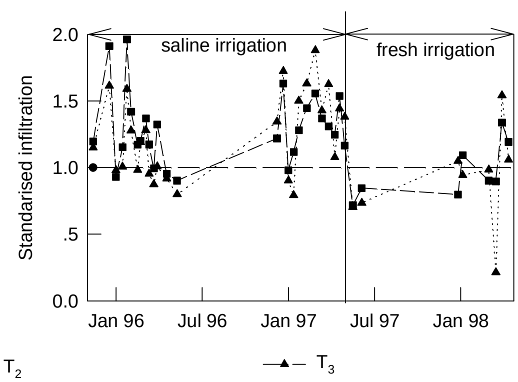


Fig 4a. Treatment impacts on Z_{vb}.

Fig 4b. Standardised infiltration.

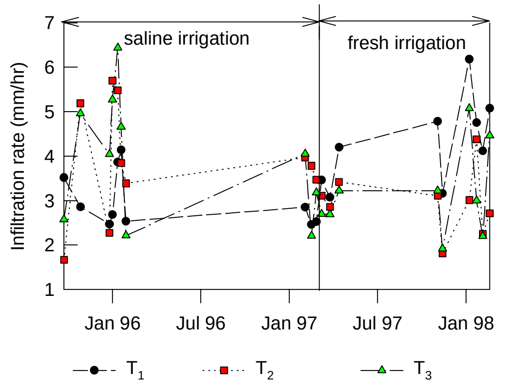


Fig 5a. Treatment impacts on Z_{ss} during trial.

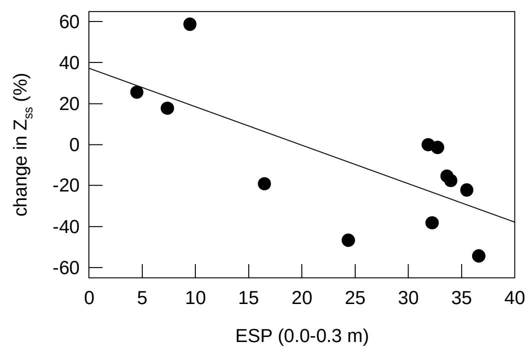


Fig 5b. Impact of ESP on change in Z_{ss}

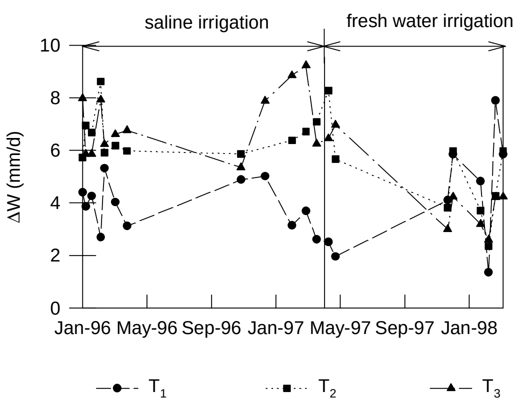


Fig 6a. Treatment impacts on ΔW.

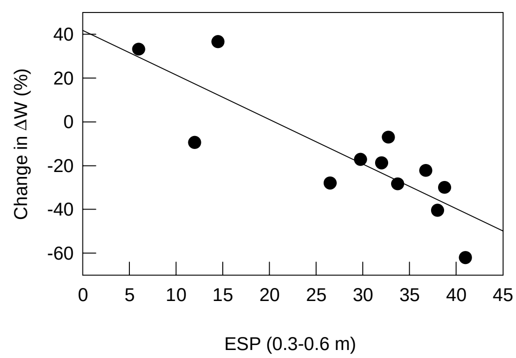


Fig 6b. Impact of ESP on change in ΔW.