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Artificial drainage affects the physico-chemical properties of salt-affected heavy clay soils in the Upper South East of South Australia

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Abstract
Artificial drainage has been widely adopted throughout the Upper South East of South Australia to intercept surface floodwaters and ameliorate dryland salinity. Land managers have reported a perceived decline in pasture productivity and the development of bare patches of soil at both drained and un-drained sites. This study aims to investigate the effects of artificial drainage on soil physico-chemical properties and to determine whether the observed plant decline is directly related to artificial drainage. Results show groundwater levels have fallen both with a decline in annual rainfall and the implementation of artificial drainage; facilitating the leaching of salts. Comparison with 1950 (pre-drainage) data confirms that a change in soil physico-chemical properties has occurred. The combination of high pH, extreme salinity and strong sodicity has led to soils that are both chemically hostile and structurally unstable; hence, plant growth is affected. Soil type and mineralogy were found to vary both across and within study sites; the un-drained smectite dominant soils exhibit the most hostile chemical conditions for plant growth. Nevertheless, the mineralogy of the soil governs the level of structural degradation when the soils are sodic, such that the illite/kaolinite-dominant soils are particularly degraded, resulting in the highly compacted form observed.

Key Words
Salinity, sodicity, alkalinity, clay mineralogy, drains, pasture decline

Introduction
Salt affected soils are widespread across Australia's arable land, severely limiting agricultural productivity. In 2001 it was estimated that 250,000 hectares or 40% of the land in the Upper South East (USE) of South Australia (SA), comprising productive farmland, native vegetation and wetlands, had been degraded by salinisation caused by high groundwater levels and flooding (National Land and Water Resources Audit and National Heritage Trust 2001). Artificial drainage has been widely adopted throughout this region to intercept surface floodwaters and ameliorate dryland salinity, and since this time, land managers have reported a perceived decline in pasture productivity and the development of bare patches of soil at both drained and un-drained sites. The primary aim of this paper is to determine the likely effects that artificial drainage has had on soil physico-chemical properties in the Keilira District in the USE of SA, and to determine whether the observed plant decline is caused directly by the drainage schemes. Annual rainfall and the implementation of artificial drainage have been considered when analysing the flux in SWL across the region, and the current condition of soils with differing drainage histories has been compared to historic data.

Methods
Three study sites, named South, Central and North, were selected for investigation, spanning a distance of 30 km, in the area locally referred to as the Keilira District, 30km inland from the coastal township of Kingston. Each of the sites had a different drainage history, including one site (North) that was not artificially drained and yet displayed patches of poor plant growth similar to those seen at the drained South and Central sites.

Historic Ground Water Trends
In order to relate changes in soil chemical characteristics to changes in soil hydrology, monitoring data were obtained for two Department of Water, Land & Biodiversity Conservation (DWLBC) observation wells located near each of the three study sites. Trends in standing water levels (SWL) were analysed against rainfall patterns and the implementation of artificial drainage throughout this region.

Soil Sampling and Analysis- historic samples
Blackburn (1952) conducted a soil survey in the Keilira-Avenue area prior to the large scale clearing of

native vegetation, agricultural development and implementation of artificial drainage in this region. The samples collected in Blackburn's study were retrieved from the CSIRO archives in Canberra and pH and EC were measured following standard methods (Rayment and Higginson 1992).

Soil Sampling and Analysis- recent study
Two soil profiles were sampled at 0.1m intervals at each of the recent study sites; representing an area of 'good' and 'poor' pasture growth. Samples were analysed for pH, EC and spontaneous dispersion following the methodology of Kelly and Rengasamy (2006). Total carbonate content (as $CaCO3$) was determined following the modified pressure-calcimeter method (Sherrod *et al.* 2002). The methods of Rayment and Higginson (1992) were used to determine CEC and Exchangeable Cations for saline soils. A method adapted from Gee and Bauder (1986) was used to determine particle size distribution. Mineralogy of the clay fraction was investigated with XRD.

Results
Significant changes in rainfall are evident in this region since the 1940s. In the years 1990 - 2008, annual rainfall only exceeds the long term mean (555 mm) four times, while the moving 5 year average fell to the lowest levels on record in 2006. This reduction in rainfall is reflected in standing water levels recorded from wells intercepting the unconfined aquifer in this region. In the northern part of the Keilira District no artificial drainage has yet been employed; however, observation well monitoring data indicate that a decline in SWL has also occurred since 1993.

Whereas the wells show seasonal variation and a strong correlation to rainfall, the data also show that SWL have been altered by the implementation of artificial drainage. The consistent minimum SWL observed for three of the observation bores for the years 1993 – 2005 indicate that the artificial drains have effectively lowered groundwater in the vicinity of the South and Central study sites. From these data we conclude that SWL are highly responsive to the implementation of artificial drainage and also to rainfall. It is therefore likely that the lowering of SWL in this region, both through a reduction in rainfall and through artificial drainage, facilitates the leaching of salts from these soils.

Mineralogical investigations of the soils confirm that there are two distinct soil types present, supporting Blackburn's observations of 1952. Given these mineralogical similarities, the soils have been grouped into two classes, smectite-rich soils and illite/kaolinite-rich soils, and compared to Blackburn's historical data (Figure 1 and 2).

Smectite - rich soils
When we compare the chemical properties of the smectite-rich soils (South 'poor', North 'good' and North 'poor') across sites, it is evident that the soil at the South site has the lowest pH, EC and ESP (Figure 1a, 1c and 1d). The analyses of groundwater levels at the South site indicate that the artificial drains have effectively lowered SWL to a consistent depth of approximately 1.2 m in autumn. The data presented in Figure 1 suggest that this lowering of SWL facilitates the leaching of salts. Hence soil pH and EC at the South site have been lowered in comparison to those of the undrained soils at the North site. The landowner at the South site has also applied gypsum (England R, pers. comm. June 2006) which, when combined with leaching, may have contributed to the significantly lower ESP observed here (Figure 1d). In comparison, soils at the North site clearly have the highest pH, EC and ESP (Figure 1a, 1c and 1d) of the smectitic soils. These characteristics can no doubt be attributed to poor internal drainage, brought about by the high clay content of the soil, the dominance of smectite minerals, the presence of a highly indurated calcrete cap at 0.6 - 0.7 m and the absence of artificial drainage throughout this area. However, the pH and EC data are not the highest reported in the historical context, as seen in Figure 1a and 1c, with the comparison to Blackburn's samples for a similar soil type (soil association J).

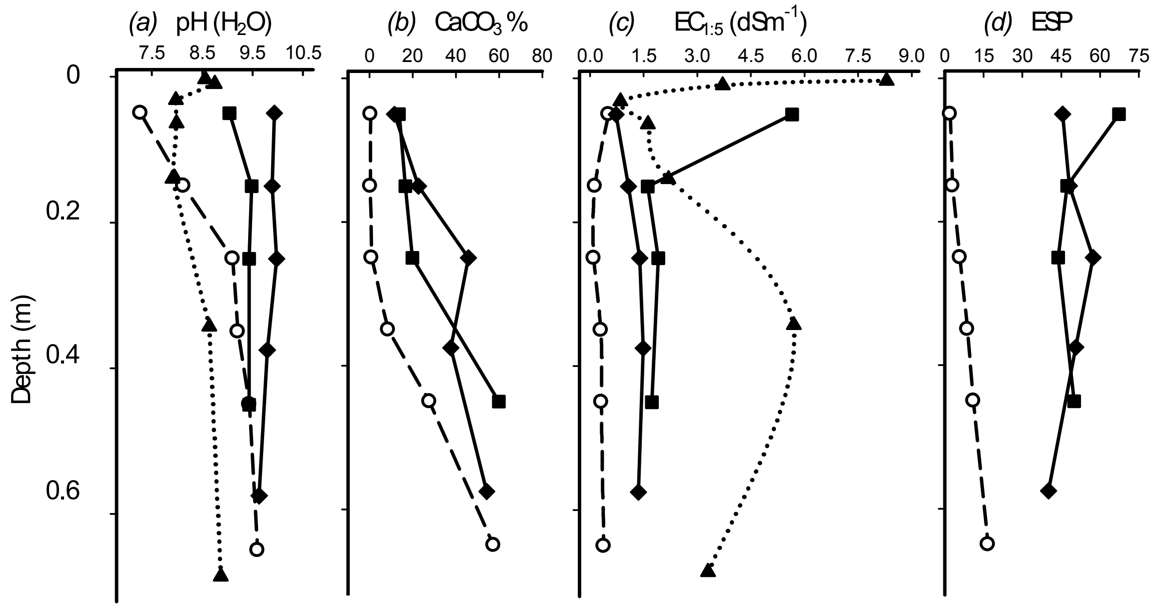

Fig. 1 Properties of smectite rich soils at the drained site, South 'poor' (○) and the undrained North 'good' (◆) and North 'poor' (■) sites, compared to the pH and EC measured for soil association J(▲) by Blackburn in 1950 prior to artificial drainage throughout this area. Open symbols are used here to represent drained sites, closed symbols for non-drained sites.

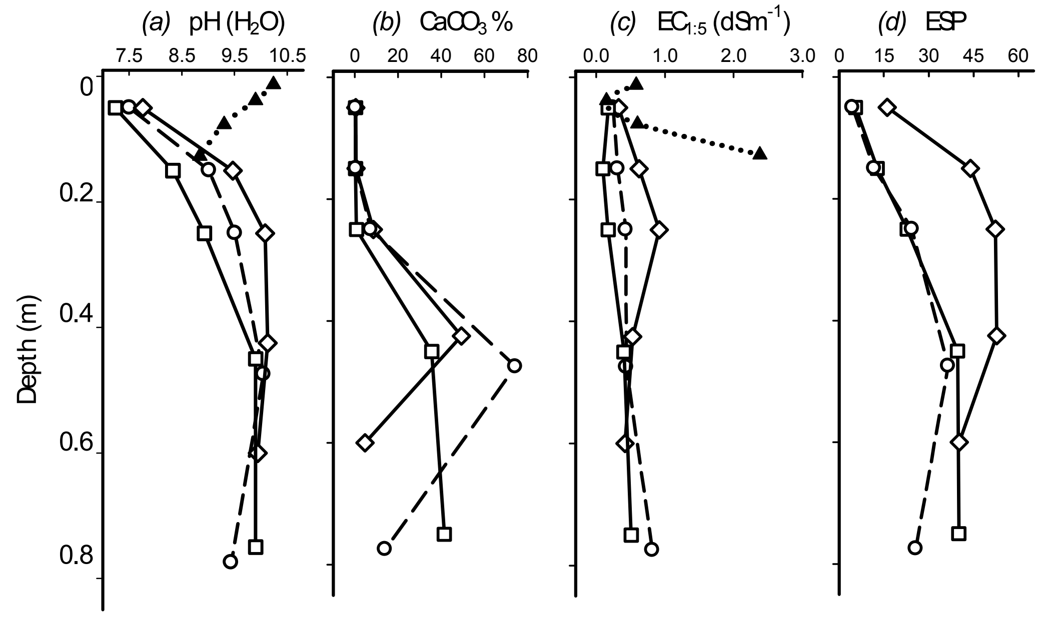

Fig. 2 Properties of illite/kaolinite-rich soils at the drained sites of South 'good' (○), Central 'good' (◇) and Central 'poor' (□) sites, compared to the pH and EC measured of soil association R (▲) by Blackburn in 1950 prior to artificial drainage throughout this area.

Illite-Kaolinite- rich soils

The observed properties of the soil profiles South 'good', Central 'good' and Central 'poor' correlate to Blackburn's Soil Association R and are rich in the clay minerals illite and kaolinite. When we compare the current properties of this soil type to Blackburn's historic data, we see that the pH and EC of these soils are generally lower than those observed in 1952 (Figure 2a, 2c). This phenomenon is attributed to the implementation of artificial drainage in this region, falling SWL and the subsequent leaching of salts from the soils at the South and Central study sites.

The nature of the clay minerals present in these soils, predominately illite and kaolinite, combined with a low to moderate salinity and high ESP in the 0.1 - 0.3 m zone results in these soils being unstable when wet (Churchman *et al*. 1993), causing them to degrade physically. Field observations during trench excavation showed that livestock movement and machinery operations caused significant structural damage when these soils were saturated. Once dispersed, the soils dry, and soil density and strength increase to an extent that they are not easily penetrated by plant roots. Subsequent water infiltration is no doubt also compromised in these dispersive soils, compounding the 'hostile' conditions for plant growth.

Conclusion

All soils investigated in the current study are very strongly alkaline, highly saline and strongly sodic at some point in their profile. Nonetheless, the soils from the study sites together exhibit wide variability in their chemical and mineralogical properties. Comparison with 1950 data confirms that a change in soil physico-chemical properties has occurred since the implementation of artificial drainage. The development of high pH, extreme salinity and strong sodicity has led to soils that are both chemically hostile and structurally unstable; hence, plant growth is affected. Soil type and mineralogy were found to vary both across and within study sites; the un-drained smectite dominant soils exhibit the most hostile chemical conditions for plant growth. Nevertheless, the mineralogy of the soil governs the level of structural degradation when the soils are sodic, such that the illite/kaolinite-dominant soils are particularly degraded, resulting in the highly compacted form observed.

From this study we conclude that the observed decline in plant growth has multiple causes; it is not related solely to the extension of the artificial drainage network, as the local farmers had feared. The most outstanding feature of these soils is the high variability of soil chemical, physical and mineralogical characteristics that were found to occur across very small distances.

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Biosolids application to salt affected soils: its effects on soil organic matter, microbial biomass and sodicity

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Abstract
Extensive areas in arid and semi arid regions around the world are salt affected. Both soil salinity and sodicity directly and indirectly affect plant growth and survival. With their characteristic low organic matter contents, sodic soils have encouraged researchers around the world to investigate possible alternative organic ameliorants which could increase soil organic matter and hence improve soil structural properties to an extent that can lead to desodification. As a result, organic matter ameliorants ranging from cottage cheese whey to green manure or pig bedding litter have been explored some with greater success than others. This study investigates the possibility of dry and wet biosolids as ameliorants improving the soil organic matter contents and its influence in reducing sodicity.

Key Words
Sodicity, organic matter, structural properties, organic ameliorants, biosolids.

Introduction
Victoria's Western Treatment Plant (WTP) at Werribee has a history of raw sewage land application supporting primary production in growing pasture that dates back to the 1890s. As a result, although being salt affected, these soils have a relatively high organic matter (OM) content (unpublished data shows these soils have an ESP in the range of 10-39 while having % OC in the range of 2.5-6.5). It is believed that sodic soils high in OM content, albeit not all types of OM, can resist dispersion well (Figure 1).

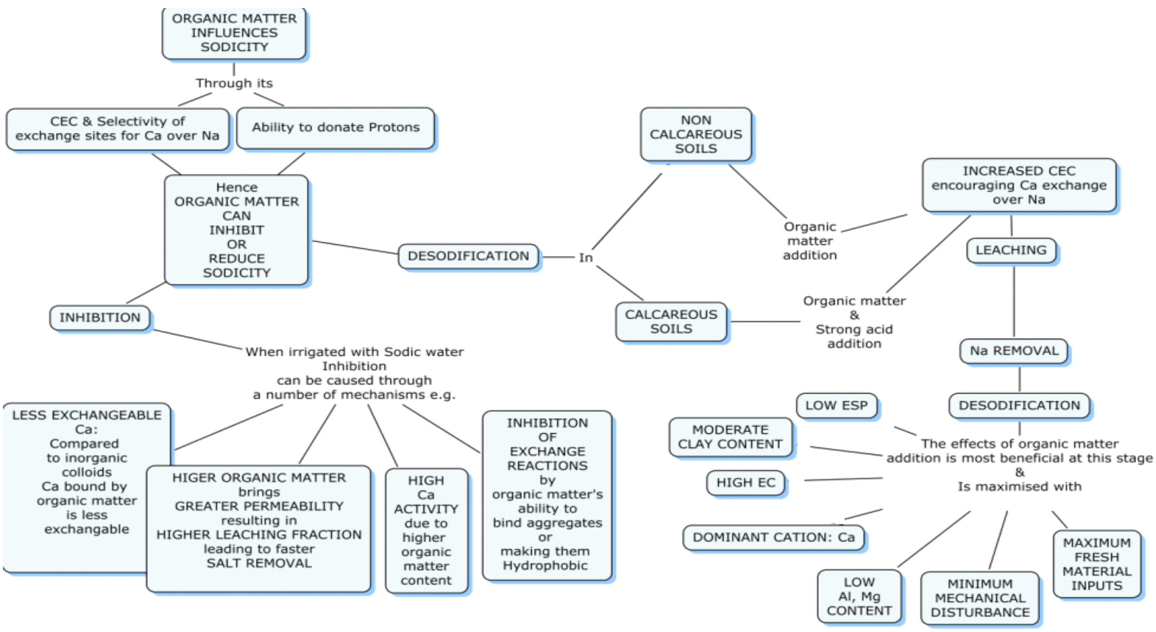

Figure 1. Influence of organic matter on sodic soil reclamation.

Since land application of raw sewage stopped in 2004, some paddocks have been dried off which neither received any irrigation nor supported any grazing. Soil samples from one such paddock were collected and soil organic matter tests carried out in late 2005 for a Masters Project. The same sites were sampled again in 2008 for this study and have shown significant reductions in %OC as shown in Figure 2.

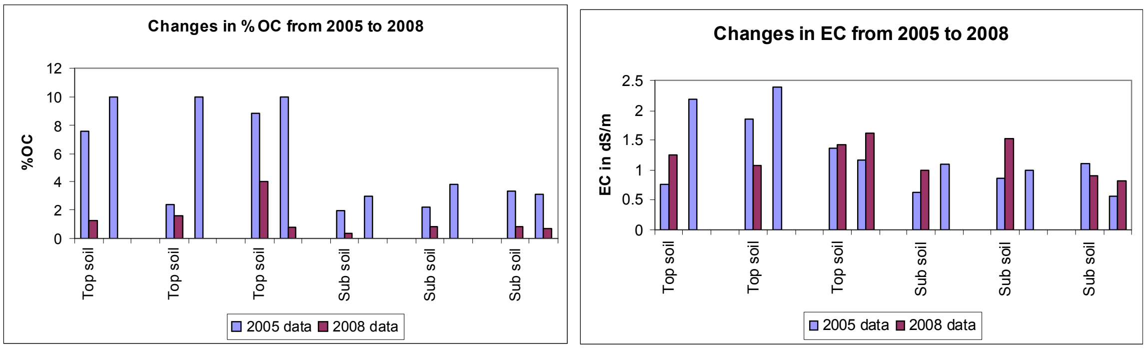

Figure 2. Changes in %OC and EC at WTP from 2005 to 2008.

Whether this reduction is significant enough to cause structural deterioration, and if they were, whether organic matter ameliorants similar to the ones these soils have previously received would be a good choice for these soils are currently being investigated. This paper only highlights the effectiveness of increasing soil OM content and Total Microbial Biomass (TMB) and their influence on sodicity. A popular approach established in the 1980's and 90's to improve soil structure in salt affected arid and semi arid regions where soil OM is low, was the incorporation of organic residues through the direct land application of either wastewater or solid and semi solid waste products (Tisdall and Oades 1982); (Angers and Carter 1996); (Haynes and Swift 1990). As shown in figure 2, the OM of the WTP soils reduces quickly if the source is removed and hence how they would respond to any organic ameliorants is worth investigating.

Soil Samples

Samples were collected in February 2008 from WTP from a paddock no longer receiving wastewater irrigation. Top soil samples were collected from the 0-100mm depth and sub soil samples were collected from the 100-300mm depth.

Sample preparation

Composite samples collected from the site were mixed uniformly using a cement mixer then potted in 16 cm diameter, 18 cm high plastic pots with openings at the bottom to facilitate drainage. Both dry (dried for 5 months on a sludge drying bed) and wet biosolids (dried for 5 weeks on a sludge drying bed) were collected from the site and blended as follows:

Profile position	Topsoil (T)		Subsoil (S)		
Water Quality	Potable Tap (D)	Tertiary Treated Sewage (R)			Raw Sewage (W)
Biolsolids mass (g/kg)-ratio dry to wet	150-100:0	150-80:20	150-60:40	50-100:0	0

Treatments were labeled with the letter in brackets following the treatment name and with the mass and ration of biosolids added. Raw Sewage was only applied to soil without biosolids added.

Irrigation Water

Each week for 24 weeks, the pots were irrigated with 100ml of Tap water, untreated Waste water or Tertiary treated Recycled water.

Table 1: Water Quality parameters (Source: measured and personal comm. with Melbourne Water)

	pH	EC (µS/cm)	BOD_5 mg/L	TSS mg/L
Tap water	7	137.6	0	0
Recycled water	8.4	1900	<10	< 5
Wastewater	7.9	2200	590	490

Methods

(1) Total Organic Carbon (Walkley-Black method) (2) Scanning Electron Microscopy (Quanta ESEM) (3) Exchangeable cations (Na, K, Ca, Mg, Al) were measured by CSBP soil and Plant Laboratory in Western Australia for ESP and Cation Exchange Capacity (CEC) measurements as well as (3) TMB.

Results

Organic amendments used to reclaim salt affected soils have been shown to improve soil stability, through enhanced soil microbial activity which transforms the newly added organic matter into materials like polysaccharides and long chain aliphatic compounds which help to bind and stabilize aggregates (Perucci 1990); (Plante and Voroney 1998). This is of course true only when the added organic matter is well decomposed and has blended properly with the aggregates. As figure 3 shows, most of the biosolids applied, did not blend well with the aggregates giving hotspots of non decomposed OM.

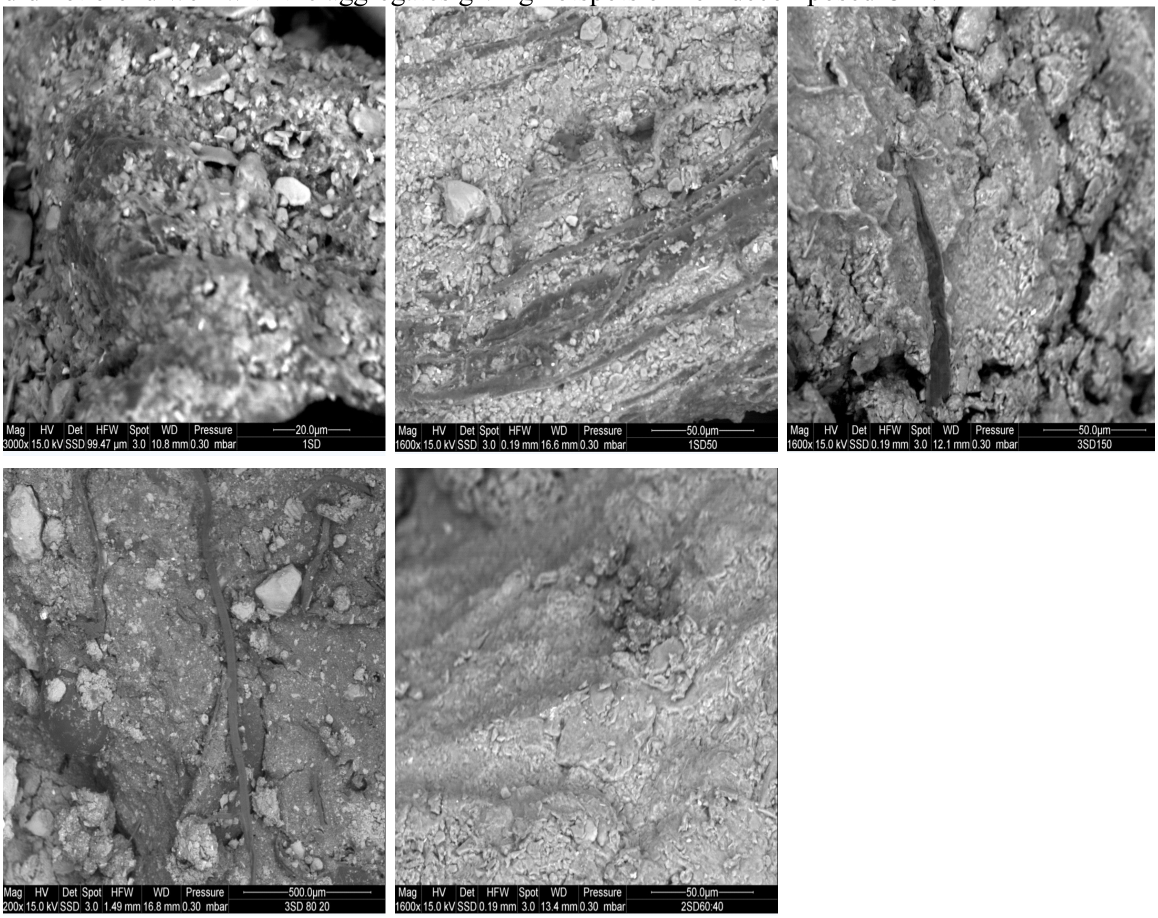

Figure 3. SEM images of sub-soil samples irrigated with tap water mixed with different proportion of biosolids amendments.

The most efficient use of added OM is probably the [the image in the bottom right] where the OM seems to have blended well to form a web over the moist aggregates. Microorganisms also promote aggregation through fungal filaments (Tisdall & Oades 1982) , or bacterial gums and exudates(Graber *et al.* 2006). From the figure 4 apart from a few exceptions (e.g. TR 80 20, TR 60 40 & SD 60 40) TMB has been seen to increase with biosolids amendment which increased CEC and decreased ESP. Dry biosolids proved to be more effective in increasing soil OM (exception: SR 60:40), CEC and TMB while reducing ESP. When the dry biosolids are blended @ 80:20 with the wet biosolids, it gives in most cases very similar results to the 150g/kg blend, but when it is blended @ 60:40 there is a marked change.

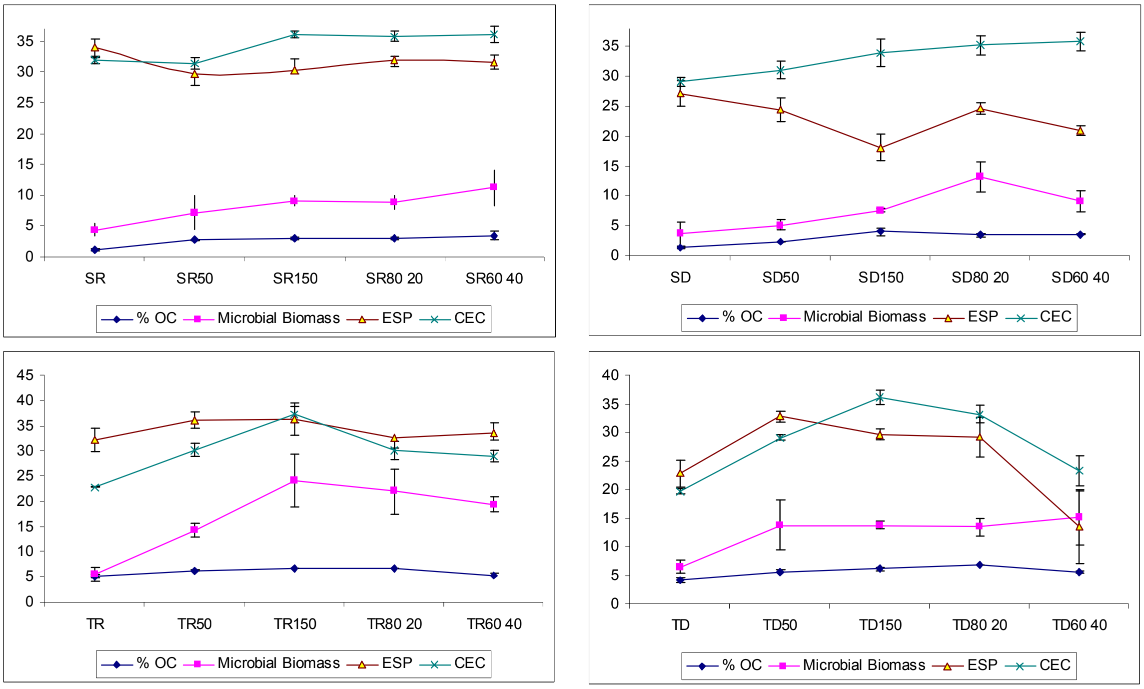

Figure 1. Changes in % OC, TMB, ESP and CEC brought about different proportion of biosolids amendments and irrigation water qualities.

Conclusion

Dry biosolids was found to be more effective in increasing the % OC, TMB and CEC while decreasing ESP (evident in the soil samples having 150g dry biosolids/kg soil) compared to the wet. The impact of these changes on the structure of these soils is still under investigation.

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Cation ratio of soil structural stability (CROSS)

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Abstract
Sodium salts tend to dominate salt-affected soils and groundwater in Australia and therefore, sodium adsorption ratio (SAR) is being used to parameterize soil sodicity and the effects of sodium on soil structure. Recent reports, however, now draw attention to elevated concentrations of potassium and/or magnesium in some soils naturally and also as a result of increasing irrigation with recycled water in Australia. Therefore, there is a need to derive and define a new ratio of these cations in place of SAR, which will indicate the effects of Na and K on clay dispersion and Ca and Mg on flocculation. Rengasamy and Sumner (1998) derived the flocculation power of these cations and on this basis Rengasamy (unpublished) defined the cation ratio of soil structural stability (CROSS). This paper gives the results of an experiment conducted on ten soil samples on hydraulic conductivity using a number of artificially prepared irrigation waters, containing different proportions of the cations Ca, Mg, K and Na. The relative changes in hydraulic conductivity of these soils reflected the flocculating power of the cations, compared to the control treatment of using $CaCl_2$ solution. Clay dispersion was found to be highly correlated to CROSS rather than to SAR.

Key Words
Sodicity, soil structure, irrigation, potassium, cations

Introduction
About 35% of total land area in Australia is affected by different categories of salt-affected soils. Apart from natural salinity, significant proportion of the cultivated land has become saline due to irrigation, particularly when groundwater or recycled waste waters were used. Sodium salts tend to dominate salt-affected soils and groundwater in Australia. When sodium ions are adsorbed by soil particles as exchangeable cations, soil becomes sodic and the soil structure is degraded by means of clay swelling and dispersion. Exchangeable potassium can also cause similar effects, but has been neglected because of low amounts present in salt-affected soils. Some studies (Emerson and Bakker 1973) have implicated the role of magnesium ions in enhancing the clay dispersion in some sodic soils.

Traditionally, exchangeable sodium percentage (ESP) is used as a measure of soil sodicity and is related to soil structural degradation through clay dispersion from soil aggregates. Critical values of ESP to define soil sodicity differs in different parts of the world because several factors including electrolyte concentration, pH, organic matter content and clay mineralogy affect the ESP value above which clay dispersion or reduction in soil hydraulic conductivity occurs. Measurement of ESP is time consuming and therefore, sodium adsorption ratio (SAR) measured in soil solution which is highly correlated with soil ESP is conveniently used as a measure of soil sodicity and, in part, the effects of sodium on soil structure.

Recent reports, however, now draw attention to elevated concentrations of potassium and/or magnesium in some soils naturally and also as a result of increasing irrigation with waste or effluent or recycled water in Australia. There is also a tendency in industries to use potassium or magnesium salts instead of sodium during process to prevent the increase in sodium concentration in effluents. Smiles (2006) reported that there is, on average, more water-soluble and exchangeable potassium than sodium across a range of soils in the Murray-Darling Basin. He concluded that neglect of potassium and simple appeal to SAR to infer soil structural stability will be misleading. Many sodic soils, particularly subsoils, in Australia have higher exchangeable magnesium than calcium. Rengasamy *et al*. (1986) concluded that the enhanced clay dispersion in high magnesic sodic soils is due to the lower flocculating effect of Mg compared to Ca.

Concept development
Sodium adsorption ratio is defined as follows:

$$SAR = Na/ [(Ca + Mg)/2]^{1/2}$$

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where concentrations of Na, Ca and Mg are expressed as mill moles of charge/L. Potassium, being a monovalent cation, can cause clay swelling and dispersion. But, potassium appears not equivalent to sodium in causing structural problems in soils (Rengasamy and Sumner 1998) although early basic colloid studies showed an almost exact correspondence between the effect of sodium and potassium in 'simple' aqueous suspensions of lyophobic colloids (Hunter 1993).

A Monovalent Cations Adsorption Ratio (MCAR), defined by

MCAR = (Na+K)/ [(Ca + Mg)/2]$^{1/2}$

has been suggested by Smiles and Smith (2004) to meet this need. This ratio may predict the adsorption of monovalent ions by soil colloids on the basis of cation exchange isotherms, but it fails to weight the relative efficacies of Na and K in the numerator and of Ca and Mg in the denominator and treats members of each pair as identical.

Therefore, there is a need to derive and define a new ratio of these cations in place of SAR, which will indicate the effects of Na, K, Mg and Ca on soil structural stability. This will be achieved using a formula analogous to the SAR but which selectively incorporates the dispersive effects of Na and K on the one hand with the flocculating effects of Ca and Mg on the other. Rengasamy and Sumner (1998) derived the flocculating power of these cations on the basis of Misono softness parameter responsible for hydration reactions and the ionic valence. They defined the flocculating power as:

Flocculating power = $100(I_z / I_{z+1})^2 Z^3$

where I_z and I_{z+1} are z^{th} and z+1 ionisation potential of a cation with valence Z. Thus, the relative flocculating powers of cations are: Na=1, K=1.8, Mg=27 and Ca=45 (see Rengasamy (2002) for details). Flocculating power gives the reverse of dispersive effects. Based on these notions a ratio analogous to the MCAR but which incorporates the differential effects of Na and K in dispersing soil clays, and the differential effects of Ca and Mg in flocculating soil clays, may be written:

Cations Ratio of Structural Stability (CROSS) = (Na+0.56K)/[(Ca +0.6 Mg)/2]$^{1/2}$

Where the concentrations of these ions (Na, K, Ca and Mg) are expressed in milli moles of charge/L (Rengasamy, unpublished). The total concentration of the cations, together with this formula should, more generally and effectively, parameterize soil structural effects of the relative amounts of monovalent and divalent cation in the soil solution than any previous approach. The development is critically important in view of current concerns about salinity definition and management in Australia.

Experimental Results

Saturated hydraulic conductivity of a clay loam soil was determined after saturating with solutions: a) pure $CaCl_2$ (0.005 M) b) SAR 10 with Na and Ca c) SAR 10 with Na and Mg d) PAR (potassium adsorption ratio) 10 with K and Ca and e) PAR 10 with K and Mg, using appropriate solutions of chlorides of Na, K, Mg and Ca. The EC of the percolating solutions were about 0.5 dS/m. The following Table shows the differential effects of Na, K, Mg and Ca on the hydraulic conductivity which is a measure of soil structural stability.

Table 1. Effect of SAR or PAR 10 solutions with either Ca or Mg as accompanying cation on soil saturated hydraulic conductivity.

Salts used	Cations	SAR or PAR	Saturated hydraulic conductivity (mm/day)
$CaCl_2$	Ca only	-	100
NaCl and $CaCl_2$	Na/Ca	10	19.8
NaCl and $MgCl_2$	Na/Mg	10	12.4
KCl and $CaCl_2$	K/Ca	10	40.6
KCl and $MgCl_2$	K/Mg	10	26.9

Ten sodic soils from different locations in South Australia were collected on the basis of different concentrations of exchangeable potassium, magnesium and calcium in addition to sodium. SAR of the soil solutions (1:5 soil-water extract) and % of clay spontaneously dispersed clay were determined by the method described by Rengasamy (2002). CROSS was also calculated using the equation given above from the concentrations of Na, K, Mg and Ca in the same soil solutions. The correlation between SAR and % dispersed clay and the correlation between CROSS and % dispersed clay are given in the following figures:

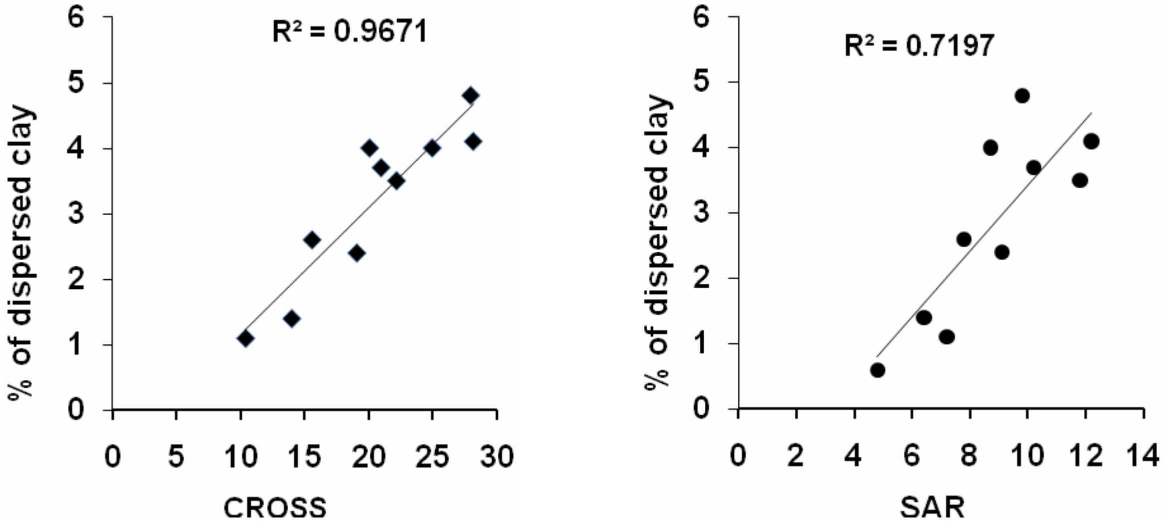

Figure 1. Relationships between CROSS, SAR and percentage of dispersed clay.

The results indicate that the correlation between CROSS and % dispersed clay is highly significant with an $R^2 = 0.9671$, a high improvement from the R^2 value for the correlation between SAR and % dispersed clay which was only 0.7197.

Further studies in progress

CROSS is a new concept and its validity is not yet tested. To validate and make use as a parameter in soils and irrigation water, our experiments are in progress to investigate the following:

Applicability of CROSS as an index of structural stability over a range of soils containing varying quantities of Na, K, Mg and Ca and also anions such as chloride, sulphate and carbonate. Similar to the utility of SAR, the effects of CROSS on structural stability will depend largely on the total electrolyte concentration and soil texture. The influence of mineralogy, organic matter and pH are also important. Researching the various factors influencing the efficacy of CROSS, we hope to derive useful threshold values.

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Change of salt-water dynamics in the Changjiang River estuary and its impacts on soil salinity

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Abstract
Long term field monitoring has been carried out for investigating change of salt-water dynamics in the Changjiang River estuary since late 1990s. Causes of salt-water dynamic change and its impacts on soil salinity are discussed and assessed in the present study. Certain regularities on salt-water dynamic change are found and possible causes of the changes are suggested, based on analyses of the salt-water data during typical years for the estuary. Decrease of the Changjiang River water level in the estuary in recent years was observed compared with that before 2003. Consequently, Electrical conductivity (EC) of the Changjiang water in the estuary increased, especially during autumn period. Electrical conductivity of both branch water of the river and ground water also trended towards increase in the estuary. Soil salinity has similar trends as water salinity in the estuary during the observed period. The Three-Gorges Project (TGP) has started operation and the reservoir water level has progressively increased since 2003. Process of the reservoir running may have certain impacts on change of salt-water dynamics in the estuary, as the coordination relation between the change and the reservoir running are observed. Considering the salt-water dynamics can also be influenced by meteorological and hydrological factors, however, contribution of the Three-Gorges Project on salt-water dynamics and soil salinity in the estuary should still be further quantitatively assessed.

Key Words
Salt-water dynamics, salinity, estuary, Three-Gorges Project, Changjiang River.

Introduction
Study on the impacts of hydropower project on environment has been conducted in some countries, e.g. the environment and social impacts assessment of the Aswan High Dam in Egypt (Abu 1989; Rashad and Ismail 2000), the impacts assessment of Livingston Dam on Trinity River in SE Texas on the dam-to-delta sediment movement (Phillips *et al*. 2004), the impacts assessment of Alqueva Dam on Guadiana River in south Portugal on the water and ecosystem in the Guadiana estuary (Luis *et al*. 2006), the impacts assessment of dams and other man-made structures on Vietnam's Mekong River on the floods and saline water intrusion in Mekong River delta (Le *et al*. 2007). Yangtze River Delta is one of the most important areas in China. With low and flat landform, however, Changjiang River estuary is affected by waterlogging and salinization threats (Xi 1994). Therefore, changes of salt-water dynamics in the Changjiang River estuary under natural and anthropogenic influences should be studied. As the largest hydropower project in the world, the Three-Gorges reservoir's regulation of water storing started in 2003. The reservoir's water level reached 135 m in 2003, 156 m in 2006 and 172 m in 2008. Previous study indicated that the project may have certain impacts on the estuary (Yu and Yang *et al*. 2008). The present paper mainly discusses changes of salt-water dynamics and possible causes of such change in the Changjiang River estuary during recent years.

Methods
Nine monitoring sites of water-salt dynamics are located along the north branch of the Changjiang River's entrance. The water level and EC (ms/cm) of the river water, branch-river water EC, groundwater EC and soil EC have been monitored every 5 day since 1998. The daily data of rainfall (mm) and evaporation (mm) in the estuary have also been collected. Seventeen sites along the north branch of the river's entrance were selected for soil sampling in autumn of each year during 1998-2008. Electrical conductivity and pH of soil extracts of the samples were measured.

Results
Water levels of the Changjiang River during some typical years are shown in Figure 1. Basically, water level of the Changjiang River continuously decreased from 2002 to 2008. Changes of the water level in autumn season were greater those of other seasons, especially during September to November. Annual average water level in 2003, year 2006 and year 2008 were all lower than during 1998-2002. Comparing with average water level during 1998-2002, water level dropped 28 cm in 2008, 25 cm in 2006, and 17 cm in 2003, respectively.

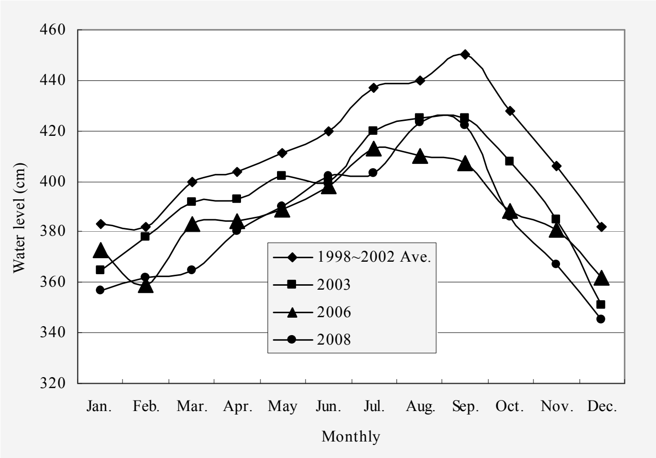

Figure 1. Water levels of the Changjiang River during different years.

Monthly water EC of the Changjiang River in Yinyang during some typical years are shown in Figure 2. Water EC of the Changjiang River showed increasing trends in 2006 and 2008, comparing average water EC during 1998 to 2002. More significant difference of the river water EC during September to October were observed between 1998-2002 and 2006-2008.

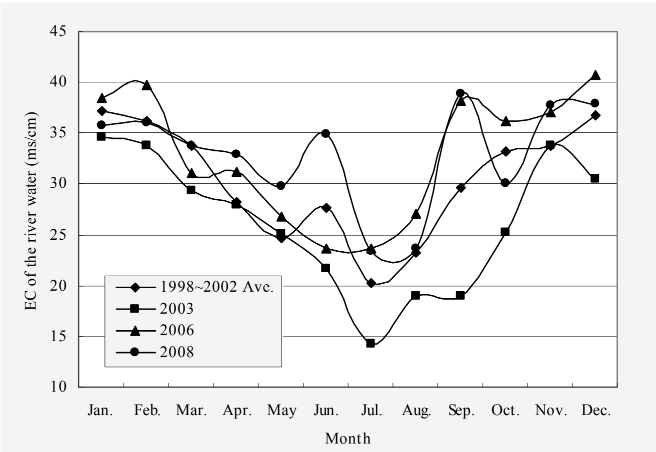

Figure 2. Monthly water EC of the Changjiang River in Yinyang during different years

Monthly water EC of the Changjiang River's branch and ground water EC during different years are listed in table 1 and table 2, respectively. Branch river water EC and ground water EC showed similar trends as the Changjiang River water. The river water EC and ground water EC in 2006 and 2008 had significant increase comparing with those during 1998 to 2002. However, both river water EC and ground water EC decreased in 2003. Soil salinity has similar trends to water salinity in the estuary during the observed period. Soil EC in the Yinyang sample site increased to 1.81 ms/cm in 2008 from 1.07 ms/cm in 2003.

Table 1. Monthly water EC of the Changjiang River's branch at Yinyang during different years (ms/cm)

Water EC of the branch	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
1998-2002 Ave.	2.88	2.79	2.95	3.14	3.13	2.47	1.87	1.55	1.67	2.40	2.97	2.55	2.53
2003	2.21	2.37	2.63	2.76	2.65	2.03	1.81	1.39	1.32	1.55	2.10	4.48	2.28
2006	2.85	2.67	3.16	2.82	2.57	2.25	1.65	2.27	2.70	3.92	4.42	2.81	2.84
2008	3.32	3.00	3.90	4.27	3.61	2.02	1.56	2.06	2.93	2.30	2.31	2.52	2.82

According to the seasonal regulation mode of the TGP (Cai *et al.* 1997), the reservoir maintains different water level by discharge during different months. At the end of flood season (October), the reservoir starts of water storing for winter electricity generation and discharge water is reduced, which may induce a decrease of river water level and may enhance seawater intrusion in the estuary during autumn. Greater increases of water and soil EC were observed in 2006 and 2008, which correspond to the reservoir's regulation processes. It may be suggested that the Three-Gorges reservoir operating may have certain impacts on change of salt-water dynamics and soil salinity in the estuary. Autumn is the major reservoir regulation season and the estuarine high-tide season. Therefore, the study of salt-water dynamics in the Changjiang River estuary and its impacts on soil salinity should be further focused in autumn. Besides Three-Gorges reservoir regulation, changes of salt-water dynamics in the estuary are also affected by other meteorological and hydrological factors. Contribution of the Three-Gorges Project to salt-water dynamics and soil salinity in the estuary should still be further quantitatively assessed.

Table 2. Monthly ground water EC during different years (ms/cm).

Ground water EC	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
1998-2002 Ave.	2.90	2.74	2.04	2.42	2.45	1.44	2.04	2.38	2.87	2.80	3.30	3.33	2.56
2003	3.34	2.63	1.75	1.75	1.70	2.00	1.69	2.03	2.50	2.75	3.02	3.06	2.35
2006	1.32	2.41	2.81	2.65	2.79	2.36	1.15	3.64	3.35	3.93	3.14	3.69	2.77
2008	3.36	1.65	3.11	3.30	3.60	1.72	1.74	3.04	2.91	3.81	3.55	3.64	2.95

Conclusion

The water level of the Changjiang River decreased in the estuary recent years, compared with the level before 2003. Electrical conductivity (EC) of the Changjiang water in the estuary increased, especially during the autumn period. Electrical conductivity of both branch water of the river and ground water also increased in the estuary. Soil salinity had similar trends to water salinity in the estuary during the observed period. Operation of the Three-Gorges reservoir may impact on salt-water dynamics in the estuary. Salt-water dynamics can also be influenced by meteorological and hydrological factors, however, impacts of the Three-Gorges Project on salt-water dynamics and soil salinity in the estuary should be further quantitatively assessed.

Acknowledgements

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Comparison of models that include salinity and matric stress effects on plant growth

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Abstract
Steady-state models provide the means to evaluate potential effects of the amount of applied water and its salinity on crop yields. These models have been in use since about 1950. Because of the inherent limitations of steady-state models, transient-state models have been under development by several research groups since about 1980. The objective of this research was to determine how the models handle matric and osmotic stress effects on relative crop ET and consequently relative crop yield.

In transient-state models, crop water use and crop yields account for the continually changing soil salinity (osmotic potential) and soil water contents (matric potential) that occur throughout the rootzone resulting from changes in irrigation water salinity, amounts of applied water, rainfall, and climate. Under conditions where crop water use is not limited by either matric or osmotic potentials or hypoxic conditions, these models assume that relative crop ET, and relative yields for forage crops, increase linearly with increasing amounts of crop water use in the range from zero to maximum potential ET. The models account for changes in this linearity if either matric or osmotic potential exceeds threshold levels.

Key Words
Salinity, modeling, relative yield, matric stress, osmotic stress

Introduction
The majority of the transient-state models evaluated in this research use Richards and the convection-dispersion equations to simulate water and salt transport (ENVIRO-GRO, SALTMED, UNSATCHM, SWAP); while others use variations of what is commonly called the 'tipping bucket' to account for water movement into and through the rootzone (SWAGMAN/WALKABOUT). One allows for preferential water flow through the rootzone (TETrans). Root and water uptake distributions in the root-zone and crop coefficients may be dependant on the stress levels within the rootzone (ENVIRO-GRO, WALKABOUT), and the effects of matric and osmotic stresses on crop water uptake can be additive or multiplicative.

Methods
For the purpose of model simulation and comparison, the same set of crop and soil data were used as inputs for the models. These were: forage corn (ECe threshold = 1.8 dS/m and slope = 7.4 %/(dS/m); moderately sensitive), and the physical properties of a Panoche Clay Loam. Meteorological data from California Irrigation Management Information System (CIMIS) at the Westside Research and Extension Center were used to schedule irrigation for irrigation options that ranged from 0.8 to 1.3 times potential crop ET. A root depth of 1 m with free drainage lower boundary condition was used in the simulations. Different EC values ranging from less than the threshold salinity to at least twice the threshold were chosen as inputs. The simulated results from various models were compared in terms of relative ET and yield of forage corn, leaching fraction, and salinity of the soil- and drainage-water.

Anticipated Results
Transient state models are useful tools that allow accounting for the effects of changes in osmotic and matric potentials on relative ET and crop yields where supplemental irrigation is practiced in monsoonal, humid, and semiarid climates. In the future, use of such models is likely to increase as irrigation water becomes more scarce and the salinity of water available for irrigation increases.

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Dryland salinity on the uplands of southern Australia: a top-down soil degradation process, or a bottom-up deep hydrology (groundwater) process?

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Abstract

In southern Australia, secondary dryland salinity has been universally linked to excess (deep) water movement in the landscape post European settlement. The reason is reported to be the extensive clearing of perennial vegetation (trees). This perception has been formulated into a simplistic, general, conceptual model to explain the formation of dryland salinity; the Rising Groundwater Model (RGM). To date, dryland salinity management strategies across southern Australia are generally targeted solely on this consensus RGM. These activities traditionally involve the planting of 'deep rooted' perennial vegetation across the hills ('recharge zones') and around the salinised zones ('discharge zones'). The objective is to reduce the amount of recharge occurring on the cleared hills and increase the vertical distance to the (ground) water-table at the discharge zones somewhere downslope. Pedological processes are rarely considered in these management activities (i.e. amelioration), and management of vegetation locally on and near the saline site is considered too difficult and ineffective a way to control water in the landscape. Water is recognized as the obvious critical factor in salinity accession and dictates outbreaks, being the 'salt transporter', but it is not necessarily the underlying cause of the increased soil salinity, especially where excess groundwater movement does not apply. This paper investigates relationships between soil/surface water, soil chemical, physical and biological attributes and vegetation parameters. Salinised and non salinised grassy woodland sites on the Southern Tablelands of New South Wales were investigated. Results suggest that increased salinity in these agricultural landscapes is a symptom of the localized, compounding effects of intensive agricultural practices (clearing, tillage and overstocking) causing degradation to soils (i.e. reduced health) and vegetation and significantly altering soil surface hydrology. Symptoms include, reduced soil organic matter (SOM) and soil organic carbon (SOC), reduced soil nitrogen, compaction and/or erosion of the A_0 and A_1 horizons with exposure of sodic, dispersible, poorly structured A_2 and sometimes B horizons (on duplex soils), altered pH levels, altered cation and anion levels, increased EC levels, and reduction in vegetative cover. Soil microbial activity is also reduced and altered. In many cases, sodium chloride, the generally designated culprit to all the problems, is not the major salt, indicating that other (toxic or reduced levels) salts also require monitoring. Using geophysical, hydrological and biological evidence, no link was found indicating that upland dryland salinity expressions are due to rising groundwater. The predominant water movement in these landscapes is surface (runoff) and lateral interflow above the semi-impermeable clay-rich B horizons. Seasonal perched water tables are common but unlikely to be a result of deeper groundwater. Sustainable remediation and management activities must be approached holistically, addressing surface water movement and use, soil health and, in endangered ecosystems, endemic vegetation. This can only be achieved following appropriate stock management.

Introduction: A big (ongoing) problem.

Secondary dryland salinity in southeastern Australia has been a high priority environmental concern for a number of decades, yet controversies still shroud a number of issues. These include the processes involved (and causes) which induce salinised soils, and consequently, its effects on the environment (biodiversity) and the way in which it is mapped and managed. Dryland salinity generally occurs in the low to medium average annual rainfall agricultural zones, where pastoralism and cropping are the dominant landuse. Much of this agriculture has been developed on low fertility, sodic duplex soils that are considered to be marginally productive, especially during drier years (drought). Although dryland salinity has been universally attributed to rising groundwater from excess water accumulation in the landscape post European settlement, many studies and insurgent management activities suggest that increased soil salinisation in southeastern Australia and indeed many upland landscapes across southern Australia, is another symptom attributed to, or a consequence of, localized surface water problems (Figure 1) and soil and vegetation degradation (e.g. Wagner 2001, 2005; Kreeb *et al*. 1995; Murray 1996; Bann and Field 2006a,b, 2007; Rengasamy 2006; Andrews 2006; Fitzpatrick 2008; Meadows 2008). This paper investigates the effects of soil degradation and associated increased salinity levels on soil biotic and abiotic parameters. Implications for sustainable management activities are discussed.

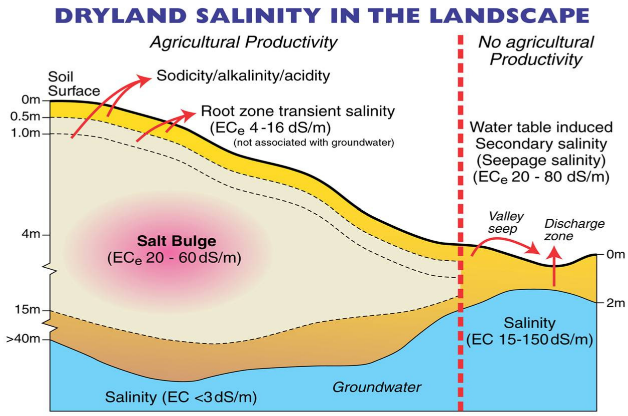

Figure 1. Transient (or surface water) salinity operates above the B horizon, which is often relatively impermeable due to the high clay proportion. This type of salinity, which has nothing to do with rising groundwater, can also occur in the lower parts of the landscape (drainage lines) where duplex soils are common (Rengasamy 2006).

Sites and methods

Many sites showing signs of dryland salinity were inspected across southeastern Australia. Nearly all sites were associated with heavy grazing by domestic livestock and many scalded areas have formed from, or contiguous to, vehicle tracks (i.e. soil degradation). Many sites inspected were not associated with cleared upper slopes (e.g. Figure 2). Ten salinised and non salinised sites (all reserves) were chosen for intensive research into salinity and regolith processes, in the agricultural zone on the Southern Tablelands NSW (STNSW), in the Upper Murray Darling Basin (Murrumbidgee/Lachlan Catchments). Most sites chosen were in a relatively non-degraded state, with remnant Yellow Box (*Eucalyptus melliodora*)/Red Gum (*E. blakelyi*) Grassy Woodlands, which are listed as an Endangered Ecological Community. Three sites had soil works installed to address surface water flow and had been partially revegetated. A suite of holistic biotic and abiotic metrics, including soil field and laboratory analyses, piezometer water table monitoring, electromagnetic induction surveys (EM31 and EM38) were undertaken during autumn and spring in 2005 and various fauna and flora surveys were performed along 50m long transects during 2004-2007. A selection of these metrics are shown in Table 1, with a results summary.

Figure 2. Dicks Creek, between the ACT and Yass, one of the most visited saline sites in NSW, if not Australia. Princes, Prime Ministers and Premiers visit the site. However, EM38 and EM31 surveys indicate low salinity levels. The site suffers severe soil erosion due to lateral movement of surface water. Note the forested ridges. The site is presently grazed by sheep, despite almost zero productivity. Revegetation attempts on the hillslopes (to the left of the photo) have done nothing to ameliorate the soil degradation problem downslope.

Table 1. Important metrics and a results summary showing the differences between relatively non-degraded soils (i.e. with an A_0 and/or A_1 horizon) and degraded soils (compacted or removed A_0/A_1 horizon) at salinised and non salinised grassy woodland sites on the STNSW. Scalds (degraded salinised areas) are included under soils without A_0/A_1 horizons.

Measurement	With A_0/A_1 horizon	Without A_0/A_1 horizon
A_0 and A_1 horizons	Present	Very thin or absent
Soil EC (1:5 – soil : water)	Generally Low levels	Low to High levels
Soil pH	slightly acidic to neutral	Acidic to extremely alkaline
EM38 (0.75m and 1.5m depth)	Low readings (non saline)	Low to High readings (saline?)
EM31 (3m and 6m depth)	Low - High readings (trees)	Low to High readings (saline?)
Soil structure	Good to very good (trees)	Very poor to poor
Soil surface compaction	Very low to high	Generally high to very high
Soil surface dispersibility	Low (slake and ASWAT)	Low to Very High
Runoff	Low to High	Low to Very High
Erosion (wind and water)	Usually low levels	Usually High (wind / water)
Soil bulk respiration (CO_2)	High rates	Low rates
Active bacterial biomass	Low levels	Zero to Low levels
Active fungal biomass	Generally zero levels	Low levels
Total fungal biomass	Very low - high	High to Very High
Total actinobacteria biomass	Zero to low levels	Low to Medium levels
Total Na	Zero to low levels	Med to Very High levels
Total Mg	Low to high levels	High to Very High levels
Exchangeable Ca	Low to High levels	Nil to low levels
Exchangeable K	Generally low levels	Low to Very High levels
Exchangeable Mg	Generally low to medium	Zero to Very High levels
Exchangeable Na	Nil to low levels	Generally High to Very High levels
Total N	Low to very high levels	Zero to High levels
SO_4	Generally zero levels	Generally High to Very High levels
Br	Generally zero - low levels	Generally High levels
Cl	Generally low levels	Generally High to Very High levels
H_2O_2 (organic material; yes/no)	Always a reaction	Nil/small reaction (zero? organics)
Soil Evaporation Potential	Low rates	High to Very High rates

Results and Discussion: Soil degradation

Results indicate that increased salinity levels on the STNSW are highly variable both temporally and spatially (horizontally and vertically), and are associated with localized soil degradation (Figure 2). Increased soil salinities are generally absent where A_0 and/or A_1 horizons are present (such as beneath trees and grass tussocks). Degraded scalded areas generally lack an A_1 horizon, exposing sodic, bleached, infertile, dispersible A_2 horizons with poor structure, low amounts of SOM, SOC and total N and P, altered pH ($pH_{(w)}$ 3.8 - 10.6 from the top 5cm soil; up to $pH_{(w)}$ 11.2 at 25cm depth), and low levels of soil microbial activity. Soil cation and anion contents analyses indicate that these are usually altered at degraded sites, including the cations Na, Mg, Ca, Fe, Al, and K and anions Cl, Br, F, SO_4 and NO_3. It is clear that many salts are present in the landscape, some of which are more toxic to plants, than simply NaCl *per se*.

The EM38/31 surveys indicated considerable temporal and spatial (horizontal and vertical) variation and show an inverse relationship between soil surface EC levels with the depth of the EM readings (i.e. decreased association from EM38 to EM31). Depth analyses between different seasons (moisture regimes) indicate that the predominant change between seasons occurred within the surface ~1m. Piezometer measurements support this, showing that the predominant water movement in these landscapes occurs as lateral interflow on top of the semi-impermeable clay-rich B horizon. Runoff following rain events is also considerable, especially where surfaces are bare and compacted (such as scalds). Seasonal perched water tables are common and no evidence was found linking rising groundwater to the saline areas.

All evidence indicates that the problem is associated with soil and vegetation degradation, causing increased surface evaporation rates and subsequent salt deposition (i.e. evaporites) derived from the surficial hydrological flow. A Soil Evaporation Potentiality Index (SEPI) was derived from a number of the indicators, thence used in the analyses, whence it yielded strong correlations with many of the biotic and abiotic attributes. An increased SEPI was associated with soil and vegetation degradation. This degradation is a consequence of a decline in soil biological, chemical and physical properties, which is predominantly process driven from the surface downwards. Much of this degradation is attributed to the compounding effects of many years of agricultural activities; vegetation and soil modification, water diversion and extraction, and stock (over) grazing and cropping. In addition, the historical effects of rabbits on the topsoil and vegetation are also likely to compound the degradation. Therefore, sustainable management needs to acknowledge the causes of these symptoms and address them appropriately.

Conclusions: Management – to improve soil 'health' and reduce surface evaporation
Soil salinity on the STNSW appears to be just one of a number of symptoms of soil and vegetation degradation caused from agricultural activities, predominantly intensive stock (over) grazing and cropping on marginal and probably already degraded land. Salinised areas often occur where rising groundwater is not the critical issue, rather, soil and vegetation degradation with increased soil evaporation subsequent to increased soil compaction and exposure, reduced organic matter (removal of A_0/A_1 horizons, occasionally the A_2) and nutrient (N, P, K) levels and altered pH levels and cation and anion concentrations. Increased evaporation rates allow increased evaporite deposition, which includes, but is not limited to NaCl. As salinity expressions on the STNSW are generally small and localized and often occur in low lying (sometimes seasonally swampy) areas of the landscape, where dispersible sodic duplex soils are common, stock control is critical for sustainable soil and groundcover management. Sites that are managed for excessive surface water flow (e.g. with the use of soil works and/or revegetation), improved soil health (e.g. increased organic matter and improved soil structure and increased water and nutrient retention) with stock exclusion usually respond favourably and relatively quickly (Figure 3).

Figure 3. Management activities focusing on grazing management and soil amelioration, in this case using exotic grass species and endemic tree species to remediate degraded salinised area to the left, and achieving desired outcomes within a relatively short time period.

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Dryland salinity, soil degradation and terrestrial biota in south eastern Australia: problems and fallacies

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Abstract

Reports suggest that dryland salinity is a major threat to terrestrial biota in southern Australia, however, very little research has been undertaken that quantitatively links secondary dryland salinity with adverse affects to terrestrial endemic biota. The research performed to date in south eastern (SE) Australia contains invalid assumptions and major problems. The abiotic and biotic principles are poorly understood.

This research investigates relationships between abiotic and biotic metrics taken at ten salinised and non-salinised sites over three years in box/gum grassy woodlands of SE Australia. Biotic surveys included site flora and fauna identification (presence), and photosynthesis efficiency in eucalypt leaves. Results indicate that many endemic fauna and flora species flourish at (highly) salinised and degraded sites; many invertebrates, mammals, frogs and lizards tolerate increased and fluctuating salinity levels. Foxes are present at all sites and are common across the study region, being an obvious major threat to all ground dwellers. Many endemic grass and tree species appear to be relatively salt tolerant, during all stages of their life cycles. This is to be expected, as southern Australia is naturally very salty. Contrary to previous reports, no direct evidence was found linking increased salinity levels with flora or fauna mortality and no evidence was found indicating that increased salinity levels favour exotic species. In southern Australia, it is problematical to directly link increased soil salinity *per se*, with ecological stress, as many other synergistic factors are involved and are probably more significant. These include the compounding adverse effects of increased soil and vegetation degradation due to past and present agricultural activities, particularly intensive livestock grazing.

Introduction

A 'threatening process'?

Quantitative research of the inter-relationships of increased soil salinity levels and endemic terrestrial biota in (SE) Australia is scarce. A number of reports claim that secondary salinisation is a major threat to endemic biota (Taws 2003; Briggs and Taws 2003; Zeppel *et al*. 2003; Thompson and Briggs 2005, Seddon *et al*. 2007), and dryland salinity is listed as a threatening process to biodiversity (EA 2001). However, the mechanisms and principals are poorly understood. Briggs and Taws (2003) extrapolate to suggest that increased salinity levels actually kill endemic vegetation and favours exotic species (weeds). However, these claims also require temporal context; increased salinity levels in southern Australia are not recent and are probably not presently extreme (Crawley 1994). Australian dryland soils are also commonly saline and sodic. Hence, it is likely that endemic biota is relatively tolerant of high and fluctuating salinity levels as suggested by Kreeb *et al*. (1995), Williams *et al*. (1998); McEvoy and Goonan (2003), Malcolm (2005); Bann and Field (2006), (2008), Humphries (2008) and Bui (2009). This paper investigates the affects of increasing soil salinity on terrestrial biota in SE Australia.

Sites

Following extensive site reconnaissance in three states, ten sites were selected with various degrees of apparent salinisation on the Southern Tablelands of NSW in the upper Murray Darling Basin. All sites contain Yellow Box (*Eucalyptus melliodora*) and Blakely's Red Gum (*E. blakelyi*) Grassy Woodlands (YBRGGW), which dominate the more productive soils of the lower slopes and drainage lines, hence, have been extensively cleared and modified for agriculture post European settlement. They are therefore listed as an Endangered Ecological Community and as dryland salinity usually outbreaks in these locations, it is listed as a threatening process (EA 2001). Sites were selected that exhibited minimal levels of disturbance, particularly stock grazing and weed incursion, to reduce these factors confounding the results. This confirmed that all sites were reserves, eight of which were travelling stock reserves (TSRs).

Methods

A suite of biotic and abiotic measurements were performed over three years to investigate interactions between the regolith and biota. Metrics included ground macro-invertebrate (pitfall traps, buried toilet roll termite baits and log disc habitat surrogates) and vertebrate surveys, flora identification and leaf analyses, various field and lab soil and water analyses and the application of the Landscape Function Analysis assessment procedure (Tongway and Hindley 2004). Abiotic metrics included soil EC (1:5w), pH (1:5w), EM38 / 31 surveys, surface compaction, SOM, SOC, CO_3 / HCO_3, slakeness, and nutrient, cation and anion analyses. A number of piezometers were installed. EC was measured at various times to investigate temporal variation. Multivariate statistical analyses were performed using GenStat 10th Edition.

Results and discussion

Sites

Most salinised sites inspected were relatively small and localised, generally less than 1 Ha in size. Sites appeared to be restricted to their current extent, showing no sign of expansion since 2004, which concurs with Wagner (2001). All sites inspected had some degree of fragmentation and/or degradation and had previously been grazed by sheep, thereby influencing soil conditions. Sites that had been fenced off from recent domestic grazing appeared to be responding favourably.

Soils

EC levels are highly variable spatially (laterally and vertically) and temporally, especially following rainfall (20.2 - 1.6 dS/m at the same location, two days apart after rain) and they are generally highest at the soil surface (i.e. from evaporation). Soil pH (w) varied considerably, from 3.8 to 10.6 in the top 5cm of soil (up to 11.2 at 25cm depth) which is an obvious determining factor for biota. Degraded scalded areas lack organic matter (SOM, SOC) and nutrients (N, P), often have increased NO_3, SO_4, Na, K, Mg, Al, Cl, F and Br, decreased Ca (and sometimes other cations) and rarely have an A_1 horizon, exposing the A_2 horizon that is generally sodic, bleached, dispersible and compacted with poor structure.

Fauna

Brush-tailed possums, swamp wallabies and eastern grey kangaroos were common at all sites. Echidnas, frogs, lizards and geckos also inhabit salinised areas. A link between elevated salinity levels and adverse impacts on ground vertebrates was not found. Anecdotal evidence suggests that mortality from foxes is a far greater threat than salt toxicity, being present at all sites. Rabbits and hares were also common. Spiders, centipedes, mites, earthworms and 11 Order of insects including termites (5 spp.), wasps and ants were identified in the salinised zones, In particular, meat ants (*Iridomyrmex purpureus*) appear to favour salinised and degraded areas, often building their large nests within the actual degraded scalded area (so-called ‘discharge zones’) where the most elevated salinity levels usually occur. Nests are occupied for long periods (years), and extend to a depth well into the subsoil, suggesting that at no period does the groundwater inundate to this level. Many other endemic ant species (>15 spp.) also tolerate the elevated salinity levels. Exotic earthworm species are the most common worms in YBRGGW, however, native species appear to be more abundant than exotic species when salinity levels increase, indicating likely superior salt tolerance. No relationship was found between salinity levels (EC) and biomass, the number of taxa identified, nor the presence of termites, ants, frogs and lizards (see Table 1).

Native trees

The rate of photosynthesis (Photosystem II), a surrogate measure for plant health, of *E. melliodora* leaves measured with a Photosynthesis Efficiency Analyser (PEAmeter) indicates that there is no significant difference between plants growing in salinised areas and those in non-salinised areas. This suggests that *E. melliodora* exhibits tolerance to increased salinity levels, which is not surprising, as all trees growing in the salinised areas, at all ages, appeared to be in a healthy state. *E. blakelyi* also germinate and persist in salinised areas and although they do suffer from dieback (widespread tree health decline), salinity cannot be directly attributed to this as suggested by previous reports. No evidence was found linking increasing salinity to dieback and/or dying trees. Many trees persist in salinised areas everywhere (i.e. in all southern states), and dieback occurs across the entire landscape, from numerous compounding and confounding factors such as drought, insect plagues, cumulative (i.e. historical) management practices including ringbarking and intensive stock grazing, modified surface hydrology and erosion. Blaming salinity for a trees poor health, which in most (all?) cases is only apparent as ‘dieback’, is unfounded. *E. cinerea, E. bridgesiana* and *E. rubida* also grow in areas with increased soil salinity.

Table 1. Summary of multivariate statistical analyses – EC ANOVA F Probability (p) using multiple regression (adjusted for position affects, or differences between). Similar results were obtained using correlation coefficients. Survey stations included buried toilet rolls used for termite baits, log discs (red gum and pine) placed on the ground as surrogate habitat and two surveys with pitfall traps. Soil $EC_{(1:5)}$ was measured at each station (surface 0-5cm).

VARIANT	EC (1:5w)
Toilet rolls eaten (termites)	X
Ants (presence – log discs, pitfalls)	X
Termites (toilet rolls, log discs & pitfalls)	X
Worms (at stations)*	√
Worms (pine log discs)*	√
Worms (red gum log discs)	X
Lizards, skinks and geckos	X
Frogs**	X
Total number of taxa	X
Log disc and Pitfall taxa number	X
Pitfall total animals (biomass)	X
H_2O_2 (reaction with soil organic matter)	√√

√√ = $p < 0.001$; √ = $p < 0.01$; X = not significant.
Data collected from 10 sites, 66 transects (50m length) and 264 stations (4/transect).
*Worms were mainly exotic spp. **The majority of frogs were found in low lying, saline areas.

Native grasses
At least six endemic grass species that are also drought tolerant and relatively productive as fodder grow in or around the salinised areas, including the most saline scalds (see Bann and Field 2006). In particular, *Cynodon dactylon* (couch grass) is common and grows on the most salinised and degraded sites. Its mat forming growth habit (rhizomes and stolons), capable of growing onto and across the scalded areas, removes the need to germinate within the hostile scalded area. Interestingly, on sites that had not been recently grazed, the boundary between grasses and the bare scalded area is usually abrupt, with no apparent adverse impact on the persisting grasses. The boundary often corresponds with a huge variation in EC and pH levels, usually within 10-20cm, suggesting a sudden change in soil conditions, or simply erosion. At a number of sites, rainfall runoff from the areas of elevated salinity (scalds) drained directly into YBRGGW, with no apparent adverse impacts on the biota.

Weeds
No evidence was found linking increasing salinity with weed dominance as suggested by previous reports, which concurs with Coutts-Smith & Downey (2006). Numerous other factors favour the incursion of weeds, especially those relating to disturbance, which must be considered when investigating the cause responsible for the presence of weeds (Coutts-Smith & Downey 2006). Evidence from this research indicates that increasing salinity favours endemic species; Australian flora and fauna have co-evolved with elevated and fluctuating soil salinity levels for millennia (Crawley 1994).

Predators
As salinity levels are highly variable, biota need to be equipped to tolerate both elevated salinity levels and the large (often sudden) fluctuations. Although some mobile invertebrate predators do not appear to be adversely affected by increased salinity levels, the affects on other functional groups is not as clear. It is likely that the presence of the meat ants in particular would deter many organisms. Areas with high salinity levels are also often bare, exposed, compacted and are often very alkaline, in addition to having formidable predators (meat ants, trapdoor and wolf spiders, wasps); a hostile and dangerous place for any ground dweller to reside. In addition, alkaline and acid soil conditions are not only toxic to the biota, they can severely reduce nutrient availability for plants.

Secondary salinity is a symptom, not a process
It appears that other important soil physical, chemical and biological parameters consequent to vegetation and soil degradation (from stock grazing and landuse practices), including compaction or erosion (removal) of the topsoil (A_1 horizon), altered soil pH levels, nutrients, cation and anion levels (Bann *et al*. this volume) and other symptoms of degradation play a more significant role on terrestrial biota recruitment, survival and persistence than salinity *per se*. It also appears that many salinity expressions are simply another symptom of land degradation, rather than the actual cause. Thence, it cannot be a threatening process. Moreover, as little

evidence was found linking increasing salinity with adverse affects to endemic biota, hence biodiversity, and high salinity levels are a natural phenomenon in this part of the world, we suggest that the habitat associated with increased soil salinity and soil degradation may actually provide an additional opportunity (ecotone) within the YBRGGW ecosystem, allowing endemic species, particularly colonisers, to thrive. This effectively paradoxically increases the overall (gamma) biodiversity levels. Further work on this matter is required.

Conclusions

Many endemic flora and fauna species flourish at salinised areas in SE Australia. This is not surprising, as salt levels in Australian dryland soils are amongst the highest in the world, and have been for millennia. Contrary to previous reports, no evidence was found to indicate that endemic flora and fauna species are directly influenced by elevated salinity levels *per se*. Indeed, a number of problems and invalid assumptions have been identified with this previous research (Bann and Field 2006, 2008). More emphasis needs to be directed towards various trials involving planting endemic grasses and trees, of local provenance, rather than the current focus on exotic and/or pseudo-exotic species (i.e. native and/or hybrid species from another state). Local provenance seed should be collected due to local ecotone variation, such as soil salinity, pH, moisture and clay content. Predicting biodiversity loss and/or ecological change in response to secondary salinisation in SE Australia requires careful consideration of site disturbance, soil degradation and all other relevant synergistic factors.

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Effect of climate on soil salinity in subboreal deserts of Asia

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Abstract
The effect of climate on soil salinity in subboreal deserts was studied on the basis of climatic parameters and data on salt-affected soils in Middle Asia (the Karakum and Kyzylkum deserts and surrounding piedmont plains), China (Xinjiang Uygur Autonomous Region, deserts of Junggar and Tarim basins), and Mongolia (the Gobi deserts). The climatic parameters in the studied subboreal deserts are different, particularly in terms of continentality, aridity, and the amount and seasonal distribution of precipitation. It is shown that there is no correlation between the climate aridity and the area of salt-affected soils. For the automorphic landscapes in subboreal deserts of Asia, the geological history of the territory and the occurrence of salt-bearing deposits are the major factors controlling soil salinity. The eolian transfer of salt-bearing material within deserts is also important. The role of climate is restricted to the redistribution of salts within the soil profiles. A different situation is observed in the soils of hydromorphic landscapes of subboreal deserts. The degree of salinity in the upper horizons of hydromorphic soils and the distribution of salts in the soil profiles largely depend on the climatic parameters. The salinity of hydromorphic soils in deserts can serve as an indicator of climate change.

Key Words
Arid regions, global change, saline soils, Central Asia.

Introduction
Salt-affected soils are obligatory components of arid environments. However, arid lands are subjected to salinization to different extents. They differ in the portion of salt-affected soils and in the degree of salinity, the chemical composition of salts, and their distribution in the soil profiles. According to Ye.V. Lobova and A.V. Khabarov (1977), arid environments occupy nearly 35% of terrestrial surface. The area of salt-affected soils on the Earth reaches 950 million hectares (Szabolcs 1989). The portion of salt-affected soils in arid lands of different continents ranges between 3 to 60% and makes up 22% on the average. The smallest portion of salt-affected soils is observed in South America and Africa; the largest portion - in Australia (Table 1). I. Szabolcs (1989) noted the areas of salt-affected soils on the Earth given by UNESCO are approximate values, because many regions do not have reliable data on salt-affected soils. However, these data suggest that the development of soil salinity in arid environments of the world differs significantly and depends on the particular region.

Table 1. The total area of salt-affected soils (thousand sq. km) and % of salt-affected soils in arid lands.

Continent	Area of arid lands (Lobova and Khabarov 1977)	Area of salt-affected soils (Szabolcs 1989)	% of salt-affected soils in arid lands
Eurasia	17992	3687.5	20.5
Africa	14654.1	805.4	5.5
North America	5771.6	177.0	3.1
South America	3673.4	1291.6	35.0
Australia	6250*	3575.7**	57.1
TOTAL	45395.7	9537.2	22.0

*According to H.E. Dregne (1976) (cited from Deserts 1986).
**The area of salt-affected soils in Australia including Oceania.

What are the reasons for this unevenness and how is it related to modern climate, in particular, to its aridity and continentality? How will soil salinity respond to climate change? These questions have yet to be solved.

In our study, we tried to find answers to them on the basis of data on soil salinity in the deserts of Middle Asia (the Karakum and Kyzylkum deserts and surrounding piedmont plains), China (Xinjiang Uygur Autonomous Region, deserts of Junggar and Tarim basins), and Mongolia (the Gobi deserts). Natural environments were under study.

Materials
Soil salinity in deserts of Mongolia was the subject of our long-term research under the aegis of the Soviet-Mongolian Biological Expedition in 1977-1991 (Soil cover and soils of Mongolia 1984; Pankova 1992). The investigation of deserts in Middle Asia was conducted by us in the 1960s-1990s (Pankova 1992). The deserts of Xinjiang Uygur Autonomous Region (**XUAR**) were studied in detail by the Soviet-Chinese expedition at the end of the 1950s (Natural conditions of Xinjiang 1960; Kunlun and Tarim 1961; Murzaev 1966) and by the authors of this paper in 2006-2008.

Climate of subboreal deserts of Asia
The studied areas belong to the zone of subboreal deserts of Eurasia; in terms of climate, it is subdivided into moderately continental (Middle Asia) and extremely continental (XUAR and Mongolia) facies (Lobova 1965). The area of our study lies within, roughly, 36-43 N and 54-67 E in Middle Asia; 36-46 N and 75-92 E in XUAR, China; and 42-45 N and 92-112 E in Mongolia. The absolute heights are about 200 m (100-400 m) in the deserts of Middle Asia; from 200 to 700 m in the deserts of Junggar basin; from 900 to 1200 m in the deserts of Tarim basin; and above 1000 m asl in Mongolian deserts.

The analysis of some climatic parameters of Mongolian, northwestern Chinese and Middle Asian deserts given in Table 2 reveals that the studied regions are quite different in terms of their climate. The most aridity and the least precipitation are characteristic of extremely arid deserts in the south of Mongolia and in the south of Xinjiang. The least continental and least arid climate is indicative of Middle Asian deserts. The northern deserts of Xinjiang and Mongolia are in the middle. It might seem that from the point of view of climatic aridity, soil salinity should develop to a greater extent in the southern deserts of Mongolia and Xinjiang. However, it is not true, actually.

Table 2. Some climatic parameters of deserts in Central (XUAR China, Mongolia) and Middle Asia (Uzbekistan)

1	2	3	4	5	6	7	8	9	10
				Mongolia					
				Northern deserts					
+3	-18.7	+23.1	2763	112	78	39	707	281	0.29
				True deserts					
+4	-18.2	+24.0	2996	90	77	42	761	303	0.24
				Extremely arid (southern) deserts					
+8	-17.0	+28.0	3648	43	31	48	911	309	0.11
				Xinjiang Uygur Autonomous Region of China					
				Northern deserts (Junggar basin)					
+5.9	-19.4	+24.7	3340	206	58	Not det.	769	302	0.22
				Extremely arid (southern) deserts (Tarim basin)					
+11.6	-5.6	+25.0	4304	38	17	Not det.	991	250	0.04
				Middle Asia					
				Northern deserts					
+8.6	-11.6	+27.0	3710	122	23	48.7	925	260	0.30
				Southern (south-Turanian) deserts					
+15.1	-0.6	+29.6	5150	125	2	63.1	1257	229	0.30

1. Mean annual temperature, °C; 2. Mean January temperature, °C; 3. Mean July temperature, °C; 4. Accumulated temperatures above 10°C, degree-days; 5. Mean annual precipitation, mm; 6. Precipitation in June–August, mm; 7. Radiation budget, kcal/cm^2 per year; 8. Potential evaporation (according to Dimo 1972): 0.72 + 0.23 · (Σt>10°C), where Σt>10°C is the accumulated temperatures above 10°C; 9. Continentality factor (according to Ivanov 1948): A · 100 / (0.33 · lat), where A is the annual amplitude of temperatures, °C, lat is the latitude of weather station; 10. Aridity factor (according to Lobova *et al.* 1977): Pr / (5.12 + Σt_{IV-X} + 306), where Pr is the mean annual precipitation, mm/year; Σt_{IV-X} is the sum of the mean monthly temperatures from April to October, °C.

Soil salinity in automorphic (with deep ground water table) landscapes
The soils of automorphic landscapes in Middle Asia are mainly represented by gray-brown soils (Calcisols, Gypsisols), takyr and takyr-like soils (Calcisols), and desert sandy (Arenosols) soils. In Mongolia and XUAR, extremely arid stony soils (Leptosols) are found along with Calcisols, Gypsisols, and Arenosols. We restricted ourselves to the analysis of gray-brown and extremely arid soils in this study.

In the gray-brown desert soils of Mongolia, salts and gypsum are mostly absent in the soil profiles and in the underlying rock. Only 10% of the gray-brown soils of Mongolia contain soluble salts; they are mainly confined to salt-bearing rocks, which are sparse in Mongolia. Extremely arid soils usually contain some amount of soluble salts; their salination originates from the eolian input of salts.

In the XUAR of China, saline and gypsiferous variants of gray-brown desert soils are more frequent than those in Mongolia. According to the Soil map of the P.R.C., 1:10 million (compiled by Ma Yonzhi, V.A. Kovda, N.I. Kondorskaya *et al.* 1959), some 70% of gray-brown soils of Xinjiang are saline or gypsiferous to some degree. There are slightly and strongly gypsiferous soils, the latter being related to paleohydromorphic conditions (Natural conditions of Xinjiang 1960).

Most (90%) of gray-brown desert soils in Middle Asia are salt-affected. Typically, they contain soluble salts in the upper 50 cm (Lobova 1965).

The main (primary) source of salts in the gray-brown soils of subboreal deserts of Asia is the parent material. Therefore, differences in the distribution of salt-affected gray-brown soils are mainly related to the geological features of the particular regions. The eolian input of salts is the secondary source of salinization of automorphic landscapes in the Middle and Central Asia. In Middle Asia, the eolian deposition of salts is most pronounced on coastal plains of the Aral Sea. It can reach 500 kg/ha per year (Kovda 1954); in some areas, the eolian deposition of salts may be up to 2-3 tons/ha per year (Glazovsky 1978). In Xinjiang, the eolian deposition of salts is most active in the areas surrounding drying salt lakes (lakes Ebinur, Aydingkul, Lopnur) and reaches 0.77 tons/ha per year on the adjacent plains (Abuduwaili *et al.* 2008). There are scarce data on the eolian deposition of salts in Mongolian deserts. Obviously, this process is less pronounced in the deserts of Mongolia than in the deserts of Middle Asia and Xinjiang because of the fewer number of the potential sources of salt removal. However, the eolian salinization of automorphic desert soils of Mongolia was described by us in the Trans-Altai Gobi Desert (Deserts of Trans-Altai Gobi 1986; Pankova 1992). It is hardly possible to relate the intensity of the eolian input of salts with the aridity and continentality of modern climate, because this process largely depends on the presence of potential sources of salts (often, the shores of salt lakes), wind conditions, and local geomorphic features in the areas of salt deposition. It is likely that Mongolian deserts are subjected to the active removal of fine earth rather than to its accumulation. The eolian deposition of salts is more intense in the studied deserts of Middle Asia and XUAR.

Soil salinity in hydromorphic (with shallow ground water table) landscapes

As a rule, hydromorphic soils in deserts of Mongolia, Xinjiang, and Middle Asia are saline and subjected to modern salt accumulation. The areas of hydromorphic soils in different regions differ significantly. In Mongolia, such soils occupy insignificantly small areas in comparison with deserts of Middle Asia and Xinjiang.

In contrast to automorphic landscapes, soil salinity in hydromorphic landscapes is closely related to climate, especially to its aridity and continentality. Thus, in extremely arid deserts of south Mongolia and south Xinjiang, "dreadful" solonchaks with salt crusts containing up to 40-60% of soluble salts in the topmost layer are found above the ground water with low solute concentrations (less than 2-5 g/l). In Middle Asia, solonchaks and even salt-affected soils are not developed in the case of such a low salinity of ground water. In Middle Asia, solute concentration of ground water in hydromorphic soils is mainly above 10-20 g/l; in this case, the content of soluble salts in the upper horizons amounts to 2% on the average (maximum 10-20%) and never reaches those high values that are observed in the south of Mongolia and south Xinjiang.

The described regularities of soil salinity in hydromorphic landscapes are governed by precipitation and temperature regimes of soils. In the south of Xinjiang and Mongolia, soils are strongly heated in summer, which leads to enhanced evaporation with accumulation of salts on the soil surface. At the same time, minute amount of precipitation excludes the leaching of salts down the soil profile. The formation of surface salt crusts is also favored by strong soil freezing, which is related to continentality of climate (there is no soil freezing in Middle Asian deserts). As a result, the migration of salts in desert soils of southern Mongolia and southern Xinjiang is unidirectional both in summer (toward the evaporative front) and in winter (toward the freezing front). In Middle Asia, the natural removal of salts from the upper horizons into the ground water takes place during the rainy season in the spring. This results in the increased solute concentrations of the ground water and the desalination of soils.

Conclusions

1. Subboreal deserts of Mongolia (the Gobi deserts), China (Junggar and Tarim basins), and Uzbekistan and Turkmenistan (the Karakum and Kyzylkum deserts and their surroundings) differ significantly in terms of the degrees of continentality and aridity of the climate and the regime and quantity of precipitation. The highest aridity is characteristic of the deserts in the south of Mongolia and south of Xinjiang (extremely arid deserts of Gobi and the Tarim basin), the lowest aridity is observed in Middle Asian deserts. The transitional position is occupied by true deserts of Mongolia and northern Xinjiang (the Junggar basin).
2. A comparison of soil salinity in deserts of Mongolia, northwestern China, and Middle Asia indicates that there is no correlation between the aridity of climate and the areas of salt-affected soils.
3. The differences in soil salinity in the automorphic landscapes of subboreal deserts of Asia are mainly related to the paleogeographic history of the landscapes, the presence of salt-bearing deposits of the past geological epochs, and the activity of the eolian transport of salts from their potential sources (shores of drying salt lakes).
4. The aridity of climate regulates the modern salt accumulation in hydromorphic landscapes: the higher the aridity, the stronger the accumulation of salts in the upper horizons of salt-affected soils.
5. The aridization of the climate may have different effects on the degree of soil salinity and on the distribution of salts in the soil profiles in dependence on their initial salinity and on the degrees of aridity and continentality of the climate and the regime of precipitation. Hydromorphic soils subjected to active modern salinization may be more sensitive indicators of climate changes than automorphic soils.

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Effect of Salinity of Tropical Turfgrass Species

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Abstract
The need for salinity tolerance of turfgrasses is increasing because of the augmented use of effluent or other low quality waters (seawater) for turfgrass irrigation. Irrigation seawater of different salinity levels (0, 24, 48, and 72 dS/m) was applied to experimental plants grown in plastic pots filled with a mixture of sand and peat (9:1).

The results were analyzed using SAS (SAS 2006) and treatment means were compared using the LSD Test. The results indicated that *Paspalum vaginatum* (seashore paspalum) (SP), *Zoysia matrella* (manilagrass) (MG), *Pasplaum vaginatum* local (SPL), *Cynodon dactylon* (common bermuda) (CB), *Cynodon dactylon* (bermuda greenless park) (GLP), *Eremochloa ophiuroides* (centipede) (CP), *Axonopus compressus* (cow grass) (CG) and *Axonopus affinis* (narrowleaf carpet grass) (NCG) experienced a 50% shoot growth reduction at EC values of 39.8, 36.5, 26.1, 25.9, 21.7, 22.4, 17.0 and 18.3 dS/m respectively, and a 50% root growth reduction at the EC of 49.4, 42.1, 29.9, 29.7, 26.0 24.8, 18.8 and 20.0 dS/m respectively. The ranking for salinity tolerance of selected grasses was SP>MG>SPL>CB>GLP>CP>NCG>CG. The results indicate the importance of the selection of turfgrass varieties according to the soil salinity and seawater salinity levels to be used for irrigation.

Key Words
Salinity tolerance, Water salinity, Turfgrass, Seawater.

Introduction
Soil salinity is considered as one of the major factors that reduce plant growth in many regions of the world. Seawater intrusion in the coastal area (McCarty and Dudeck 1993) has added to the salinity problems in turfgrass culture. Moreover, sea water, as a secondary water source, is increasingly being used to irrigate large turf facilities (Arizona Department of Water Resources 1995). Salt tolerant turfgrasses are becoming essential in many areas of the world including Malaysia because of salt accumulation on soil, restriction on ground water especially in costal areas (Hixson *et al*. 2004). Therefore, the need for salt tolerant turfgrasses has increased (Harivandi *et al*. 1992). A new generation of salt-tolerant turf varieties might allow landscape development in saline environments and might be ideal in such environments where salt water spray is a problem, or where limited or no fresh water is available for irrigation. The proper utilization of highly salt tolerant turfgrass species will give benefit to turfgrass areas in Malaysia. The objective of this study was to determine the relative salt tolerance and growth response of warm season turfgrass species grown on sand culture.

Methods
The experiment was conducted with eight turfgrass species in the glasshouse of Faculty of Agriculture at Universiti Putra Malaysia under sand culture system. The soil was sandy with pH 5.23, EC 0.3 dS/m, OC 0.69%, sand 97.93 %, silt 1.89% and clay 0%. The diameter of plastic pots was 14 cm with 15 cm depth. The average day temperature and light intensity of glasshouse were 28.5-39.5 ^{0}C and 1500-20400 lux respectively. Four salt water concentrations namely T_1= 0, T_2=24, T_3= 48, T_4=72 dS/m were applied in this study. Untreated checks (T_1) were irrigated with distilled water. NaCl was added to seawater for T_4 to obtain the salty water level of 72 dS/m. To avoid salinity shock, salinity levels were gradually increased by daily increments of 8 dS/m in all treatments until the final salinity levels were achieved. After the targeted salinity levels were achieved, the irrigation water was applied on daily basis for a period of four weeks. Data were collected on leaf firing, shoot and root growth, turf quality. Leaf firing was estimated as the total percentage of chlorotic leaf area, with 0% corresponding to no leaf firing, and 100% as totally brown leaves. At the end of the experiment shoots and roots were harvested and were washed with deioniozed water and dried at 70 ^{0}C for 72 hrs. The experimental design was a randomized complete block design (RCBD) with five replications.

Results

Shoot and root growth rate gradually decreased as the salinity increased. Relative shoot-root growth (as a % of control) decreased with increasing salinity in all species (Figure 1a & b). Results indicated that *Paspalum vaginatum* (seashore paspalum) (SP), *Zoysia matrella* (manilagrass) (MG), *Pasplaum vaginatum* local (SPL), *Cynodon dactylon* (common bermuda) (CB), *Cynodon dactylon* (bermuda greenless park) (GLP), *Eremochloa ophiuroides* (centipede) (CP), *Axonopus compressus* (cow grass) (CG) and *Axonopus affinis* (narrowleaf carpet grass) (NCG) experienced a 50% shoot growth reduction at the EC of 39.8, 36.5, 26.1, 25.9, 21.7, 22.4, 17.0 and 18.3 dS/m respectively, and a 50% root growth reduction at the EC of 49.4, 42.1, 29.9, 29.7, 26.0 24.8, 18.8 and 20.0 dS/m respectively. Marcum and Murdoch (1994) also reported that relative shoot growth was reduced by 50% at the salinity level of 36.4 dS/m NaCl in *P. vaginatum* and 35.9 dS/m in *Z. matrella* which is in agreement with our present study.

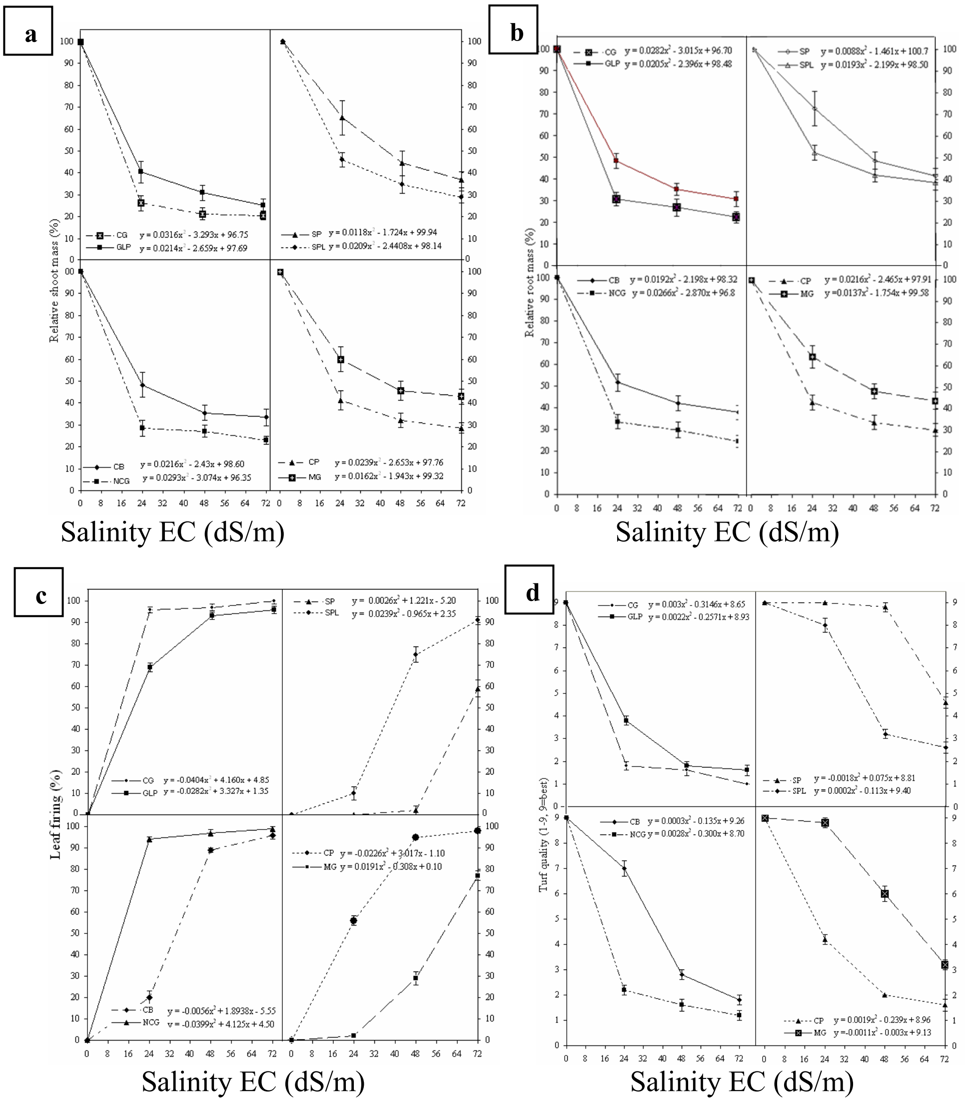

Figure 1. (a) Relative shoot growth (b) root growth (c) leaf firing (d) turf quality of *Axonopus compressus* (CG), *Cynodon dactylon* (GLP), *Paspalum vaginatum* (SP), *Paspalum vaginatum* local (SPL), *Cynodon dactylon* (CB), *Axonopus affinis* (NCG), *Eremochloa ophiuroides* (CP) and *Zoysia matrella* (MG) at different salinity levels.

Regardless of turf grass species, leaf firing increased with increasing salinity, reaching 94-100% at the extreme salinity treatment of 72 dS/m (Figure 1c). However, there was less salinity injury noticeable in *P. vaginatum* and *Z. matrella* at all salinity levels compared to other grasses. Leaf of *P. vaginatum* was unaffected at 24 dS/m while at 94-100% leaf firing was noticeable in *A. affinis* and *A. compressus*. However, leaf firing was moderately similar (55%) in *E. ophiuroides* and *C. dcatylon* at 24 dS/m. At 48 dS/m leaf firing was high in *A. affinis* (97%) and *E. ophiuroides* (96%) while 69 % to 92% in *C. dactylon* (Figure 1c). The least leaf firing (59%) was observed in *P. vaginatum*. The same trend was observed at 72 dS/m, where 90-95% leaf firing was observed in *C. dcatylon*, *P. vaginatum* local, *C. dactylon*, *E.*

ophiuroides, A. affinis and *A. compressus*. *P. vaginatum* and *Z. matrella* were moderately affected with 59% and 81 % respectively. Turf quality under salt stress as indicated by visual ratings is presented in (Figure 1d). Turf quality decreased with increasing salinity level. Turf quality decreased severely in *A. affinis* (NCG) and *A. compressus* (CG) while *P. vaginatum* (SP) and *Z. matrella* (MG) exhibited the best turf quality among the entries at all salinity levels.

Conclusion

The relative salinity tolerance of turfgrass root growth, shoot growth and leaf firing were closely associated with salinity tolerance of the grasses. The different species of grasses were grouped for salinity tolerance on the basis of 50% shoot and root growth of reduction, leaf firing and turf quality with increasing salinity. The first groups was the most tolerant species including *P. vaginatum* (SP) and *Z. matrella* (MG) which were able to tolerant high levels of salinity between 36.5 to 49.4 dS/m. In the second group were the moderate tolerant species including *P. vaginatum* local (SPL), and *C. dactylon* (CB) which were able to tolerate salinity level between 25.9 to 29.9 dS/m, while in the the lowest tolerant performance group were *C. dactylon* (GLP), *E. ophiuroides* (CP) *A. compressus* (CG), *A. affinis* (NCG) varieties, which were affected at salinity level of between 17.0 and 26.0 dS/m.

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Effects of an alternative water source and combined agronomic practices on soil salinity and irrigated cotton in coastal saline soils

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Abstract
The ongoing experiment for cotton (*Gossypium hirsutum L.*) was conducted at the Zhongjie Farm, Huanghua city of Hebei province in the coastal salinity-affected areas in North China Plain, to determine the effects of alternative irrigation water sources /methods and agronomic practices on changes in soil water-salt contents and soil pH during cotton growth stages, and also on seedling emergence and yields of cotton. The experiment was set-up using split-plot design with two water sources as main treatments (well water /desalinized sea-ice water); two irrigation methods (+PAM (Polyacrylamide) /-PAM); and four fertilization modes: check (CK), mineral fertilizer (F), mineral+organic fertilizer (FM), and mineral fertilizer+gypsum (FG). The 10-cm top-soil salt contents at seeding decreased by about 18%, 32%, 34% and 55% with F, FM, FG and PAM under well-water irrigation, respectively, and by about 40%, 23%, 23% and 58% with F, FM, FG and PAM under sea-ice water irrigation, respectively, as compared with PAM-untreated CK. Using PAM-treated irrigation, the 10-cm top-soil salinity significantly decreased to about 2.3-3.9 g/kg from 4.6-8.6 g/kg (PAM-untreated). The top-soil salt contents at seeding stage also adversely affected seedling emergence (r = -0.71**), and resulted in yield reduction (r = -0.50**). PAM-treated irrigation, either using well-water or desalinized sea-ice, in combination with gypsum, shows the best practice for soil desalinization, and hence seedling emergence and cotton yields, and could be acceptable for crop irrigation in the coastal saline areas.

Key Words
Coastal areas, cotton, fertilization, irrigation, polyacrylamide.

Introduction
The coastal area surrounding the Bohai Sea (including 3 provinces and 2 cities, viz. Hebei, Liaoning, Shandong, Tianjin and Beijing) is one of the important key regional economic development belts and food production bases in China. Fresh-water shortage is the most limiting factor to crop production in the coastal areas surrounding the Bohai Sea, thus searching for usable water resources and effective water-saving irrigation methods for improvement of crop production on the salinity-affected land has been of a great interest in recent years. The use of "new water" through desalinisation of seawater or brackish water for crop irrigation has been also receiving great attention in water-starved countries throughout the world (Fang and Chen 1997; Wolff and Stein 1999; Pereira *et al.* 2002; Qadir *et al.* 2003; Qadir and Oster 2004; Li *et al.* 2008; Zhao *et al.* 2008). In China, recently the sea-ice resource of Bohai Sea has been considered to be a potential resource of fresh water (Shi *et al.* 2003; Li *et al.* 2005). Shi *et al.* (2003) observed in the investigated area in Behai Gulf that salt separation from sea ice in freezing process results in lower salinity (about 1.4-4.0 g/L) in sea ice with an average of 2.64 g/L, far less than that of sea water (about 26-29 g/L). The salinity of refrozen sea water ice decreases further to 0.5-2.0 g/L, close to the salinity of freshwater (Shi *et al.* 2003).

Using melt and desalinized sea-ice water for crop irrigation has been tested with simple and low-cost desalinization techniques (by sea-ice freezing-melting processing through temperature control) under the recent research project support in China (Xu *et al.* 2006; Zhang *et al.* 2006; Hu *et al.* 2009; Zheng *et al.* 2009). However, under the saline conditions, influenced by capillary up-flow from salt-rich shallow ground water, irrigation should meet both the crop water requirements and the leaching (or desalination) requirements (Minhas 1996). Thus, integrated irrigation management, combined with other agronomic practices, including hydraulic, physical, chemical, biological and engineering practices, may help both increase the efficiency of infiltration and use of irrigation water, and improve the efficiency of the reclamation, amelioration and utilization of salt-affected soils. Whether sea ice can be used as freshwater also depends on the salinity and alkalinity of the thawed sea ice (Shi *et al.* 2003). However, the changes in soil water salt contents and salinity and alkalinity relations when the sea-ice water is used for crop irrigation are still unclear.

The objective of the research is to determine the effects of various irrigation (water sources /water additives by PAM) and fertilization practices (soil amendment additions by gypsum or organic fertilizer combined) on the changes in soil water-salt contents and soil pH during cotton growth stages, and on cotton seedling emergence and yields, to provide an assessment of using desalinized sea-ice water as an alternative irrigation water source and integrated agronomic practices of soil water-salt management for cotton production in the salinity-affected and freshwater-limited coastal areas of the Bohai Sea in China.

Methods

The ongoing field experiment was carried out at the Zhongjie Farm, Huanghua city of Hebei province (117°23'-117°29'E, 38°19'-38°29'N, located in dry semi humid region of northern China), on a loamy-clay soil with a moderate - high salinity level, in the coastal area near the Bohai Sea in China. The initial 20 cm layer salt contents ranged from 4 to 11 g/kg due to field flooding in 2006. Soil pH was about 8.4. The groundwater table level is around 0.9-1.6 m deep. The average annual rainfall is about 620 mm. Spring cotton (Gossypium hirsutum L.), one crop per year, is one of the dominant crops. Spring drought, accompanying high salinity at the soil surface inhibits seed germination and seedling emergence, which in turn adversely affects cotton growth and yields. Thus, irrigation is necessary to alleviate both water and salt stress The experiment was set-up using split-plot design with two water sources as main treatments: well-water and desalinized sea-ice water; two irrigation methods as sub-treatments (+PAM (Polyacrylamide)/-PAM); and four fertilization methods as sub-treatments: 1) CK， 2) mineral fertilizer (F), 3) mineral + organic fertilizer (FM), and 4) mineral fertilizer + gypsum (FG). The salt contents of well-water and desalinized sea-ice water were about 1 and 3 g/L, respectively. Mineral fertilizer applications were 180 N (urea, 46% N), 150 P_2O_5 (superphosphate, 12% P_2O_5), and 90 K_2O kg/ha (Potassium fertilizer, (K_2SO_4, 50% K_2O). Commercial organic fertilizer application was 4500 kg/ha. The contents of organic carbon, total N, total P, total K and moisture were 38%, 2.35%, 1.39%, 1.25% and 42.9%, respectively for organic fertilizer. Gypsum and PAM applications were 5000 kg/ha and 10 ppm, respectively. Plots of 6 x 5 m^2 were laid down randomly in triplicate.

The pre-field experimental preparation for cotton crops was conducted in April 2007. To lower the ground water-table against soil water-logging and salinity-rising, a raised bed with drains around was built in the experimental site field. Irrigation water (about 55.5 mm) and fertilizer treatments were implemented before cotton crop planting (on the 27th of April). The 2nd irrigation treatment was on the 6th of July. Cotton was seeded in early May (the 2nd of May), at distances of 60 cm and 80 cm between rows and at 30 cm within the rows. The local salt-tolerant spring cotton (*Lumianyan no. 21*) variety was used. To prevent evaporation and salinity-rising, plastic film cover was practised on the seeded soil surface at sowing.

Soil samples were collected at depths of 0-10, 10-20, 20-40, 40-60, 60-80, and 80-100 cm for soil moisture, salt content, and pH value determination taken at seeding and main growth stages of cotton. Electrical conductivity (EC) and pH value were measured in a 1:5 (by weight) soil-water extract using an EC/pH meter WM-22EP. Soil salt content can be converted by the relationship of total dissolved salts (TDS) to EC as follows:

$$\text{TDS (mg/L)} = \text{EC } (\mu\text{S/cm at } 25℃) \times 0.6 \quad (1)$$

Seedling emergence and cotton yields were measured at seedling stage (29 May) and harvest (23 October), respectively. Statistical analysis was done with the GLM /REG procedure of the SAS Institute, Inc. (2004).

Results

Changes in top soil salt contents and pH at cotton growth stages

Mean soil salt contents and soil pH in the top 10 cm layers changed during the cotton growing periods as shown in Table 1. Mean 10-cm top-soil salt contents greatly changed from 4.8 g/kg (ranging from 1.8 to 15.5 g/kg) at seeding to 2.3 g/kg (ranging from 1.0 to 6.3 g/kg) at harvest with increased seasonal rainfall between July and Sept.; while mean 10-cm top-soil pH slightly changed from 8.5 (ranging from 7.9 to 9.1) at seeding to 8.4 (ranging from 7.95 to 8.93) at harvest.

The big variation in top-soil salinity at seeding was related to the top-soil redistribution because of pre-field preparation in April of 2007, and flooding in 2006 (in which cotton yields were heavily lost due to waterlogging and salinity). The salt contents of the 10-cm top-soil at seeding were also influenced by various irrigation and fertilization treatments, decreasing by about 18%, 32%, 34% and 55% with F, FM, FG and PAM under well-water irrigation, respectively, and by about 40%, 23%, 23% and 58% with F, FM, FG and PAM under sea-ice water irrigation, respectively, as compared with PAM-untreated CK (data not shown). Either using well-water or desalinized sea-ice water irrigation with PAM application, the 10-cm top-soil salt contents significantly decreased to about 2.3-3.9 g/kg (+PAM) from 4.6-8.6 g/kg (-PAM) ($P<0.05$).

Table 1. Statistical data for cotton yield (kg/ha), soil salinity (g/kg) and pH in 10-cm top-soil layers (n=48) measured during the period of May 2 at seeding to Oct 27, 2007 at harvest.

Iterm	Salinity _May 2	Salinity _July 10	Salinity _Sept 15	Salinity _Oct 27	pH _May 2	pH _July 10	pH _Sept 15	pH _Oct 27
Min.	1.8	1.2	1.7	1.0	7.90	7.91	7.50	7.95
Max.	15.5	18.9	13.9	6.3	9.09	9.06	8.74	8.93
Mean	4.8	5.9	5.6	2.3	8.51	8.38	8.10	8.40
SE.	0.4	0.6	0.4	0.2	0.04	0.04	0.04	0.03
SD.	2.9	4.2	2.9	1.1	0.27	0.25	0.30	0.23
CV(%)	59.8	70.3	53.0	45.5	3.1	3.0	3.8	2.8

Relationships between cotton seedling emergence /yields and top soil salinity /pH

Relationships between cotton seedling emergence /yields and the 10-cm top-soil salt contents /pH are shown in Table 2. The 10-cm top-soil salt contents during cotton growth stages, especially at seeding stage (for May 2) adversely affected seedling emergence (r = -0.71**), and significantly resulted in yield reduction (r = -0.50**). Cotton yields significantly decreased with a reduction in seedling emergence (r = 0.62**), related to the 10-cm top-soil salt contents at seeding, but not to the top-soil pH values. Apparently, the 10-cm top-soil salt content at cotton seeding is the most important yield-limiting factor. Although generally there were significant negative relations between the 10-cm top-soil salt and pH during cotton growing periods, they have less impact on cotton yields than the soil salt content at seeding stage.

Table 2. Correlation coefficients (r) for cotton yields (kg/ha), seedling emergence (%), and the 10-cm top-soil salt contents (g/kg) and soil pH measured during the periods of May 2 to Oct 27, 2007.

Item	Cotton Yield	Seedling emergence	Salinity _May 2	Salinity _July 10	Salinity _Sept 15	Salinity _Oct 27
Seedling emergence	0.624**					
Salinity_May 2	-0.499**	-0.708**				
Salinity_July 10	-0.400*					
Salinity_Sept 15	-0.278					
Salinity_Oct 27	-0.079					
pH_May 2	-0.297	0.141	-0.428**			
pH_July 10	-0.057			-0.689**		
pH_Sept 15	0.104				-0.440**	
pH_Oct 27	-0.125					-0.703**

Note: * and ** refer to significance at P< 0.05 and P< 0.01 respectively.

Relationships between profile soil salinity and moisture / pH

The correlation coefficients (r) between soil moisture and salinity at seeding show positively significant relations when PAM treated, but insignificant relations for untreated soil in the 0-10, 10-20, and 20-40 cm soil depths (Table 3).

Table 3. Correlation coefficients (r) for soil salinity (g/kg) versus moisture (%) /pH in the 0-10, 10-20, 20-40, 40-100 cm soil profile at seeding (May 2, 2007).

Irrigation method		Soil moisture 0-10 cm	10-20 cm	20-40 cm	40-100 cm	Soil pH 0-10 cm	10-20 cm	20-40 cm	40-100 cm
	Soil salinity								
+PAM	0-10 cm	0.355*				-0.116			
	10-20 cm	0.631**	0.436*			0.158	-0.348		
	20-40 cm	0.599**	0.549**	0.452*		0.200	-0.187	-0.025	
	40-100 cm	0.410**	0.502*	0.372	0.194	0.178	-0.050	0.253	-0.166
-PAM	0-10 cm	-0.275				-0.792**			
	10-20 cm	0.145	-0.081			-0.262	-0.588**		
	20-40 cm	0.049	-0.162	-0.335		-0.617**	-0.350	-0.612**	
	40-100 cm	-0.144	-0.271	-0.328	-0.298	-0.508**	-0.200	-0.417	-0.652**

Note: * and ** refer to significance at P< 0.05 and P< 0.01 respectively.

Soil moisture contents in the top 0-10 and 10-20 cm were also positively related to the deep soil salinity when PAM treated, showing that PAM-treated irrigation promoted salt downward transfer with irrigation water movement due to increased infiltration rate. The relationships between profile soil pH and salinity at seeding were not significant when PAM treated, while negative significant relationships between them were found in the 0-10, 10-20, 20-40 and 40-100 cm soil depth when untreated (Table 3). This indicated that the decline in salt contents in soil profiles with PAM-treated irrigation did not cause a significant increase in profile soil pH values.

Conclusions

The PAM-treated irrigation, either using well-water or desalinized sea-ice, combined with gypsum is best practice for soil desalinization from top to deep soil layers, and hence seedling emergence and cotton yields. The desalinized sea-ice water used as an alternative water source for crop irrigation in the salinity-affected coastal areas could be effective using an integrated agronomic practice (such as PAM-treated irrigation combined with gypsum application).

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Effect of chloride and sulfate salinity on nutrient uptake in Iranian rice (*Oryza sativa* L.)

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Abstract

Most of the studies on crops exposed to salinity stress under controlled in vitro conditions have used single salts only, usually NaCl. Studies involving the usage of natural salts mixtures of NaCl and Na_2SO_4 have been very few. Therefore a greenhouse experiment was conducted to determine the effects of both NaCl and Na_2SO_4 on mineral nutrient status of rice. Rice seedlings were hydroponically exposed to different salt concentrations and compositions for 21 days. The results revealed that only the root length was decreased by increasing salt level. The amounts of Na^+, K^+ and Mg^{2+} of shoot and root tissues increased at high salt levels. However Ca^{2+} content of root decreased with increasing salinity level. The Na^+/K^+ ratio was maintained in both shoot and root under salinity condition. An antagonistic effect between SO_4^{2-} and Ca^{2+} uptake was observed. A careful consideration of cation concentrations in shoots indicated that there is a gradual increase in Na^+ while K^+, Ca^{2+} and Mg^{2+} remained almost constant with salinity levels up to 5 dS/m. It is assumed that the composition of sodium salts plays a functional role in cationic balance within the Fajr genotype. As a conclusion the response of plant to salinity depends upon salt compositions.

Key words

Rice, salt stress, sodium salt compositions, mineral nutrients, nutrient imbalance.

Interaction

Salinity is a major constraint to rice production. Development of management alternatives (Shannon 1997) and improvement of salinity tolerance in current cultivars (Epstein *et al.* 1980) are the strategies for reducing salinity impacts in crop production. It was documented that many species have the ability to compartmentalize and accumulate Na^+ and Cl^- in older leaves. Only at high salinity levels, or in sensitive species which cannot control Na^+ transport or compartmentalize the ions, the ionic effect dominates the osmotic effect (Munns and Tester 2008). toxic ionic effects of excess Na^+ and Cl^- uptake, and reduction in nutrient uptake (K^+, Ca^{2+}) because of antagonistic effects, are effects of salinity on rice growth (Dobermann *and fairhurst* 2000). The high salinity increases sodium concentration and sodium uptake. During a long time in salinity, therefore, the sodium toxicity cause to reduce the yield (Castillo *et al*. 2003). There are antagonistic effects on nutrient uptake by plants that cause nutrient disorders particularly of K and Ca under salinity conditions. Excessive Na^+ concentration inhibits Ca^{2+} uptake in many plants (Grieve and Fujiyama 1987; Dobermann *and Fairhurst* 2000). Rice as a salt-sensitive crop is a species native to swamps and freshwater marshes and its cultivated varieties provide one of the world's most important food crops. Salinity stress causes a number of effects on plants such as osmotic effects, ion toxicity and nutrient imbalance. Whereas in nature the soil solution is a complex mixture of various cations like Na^+ and Ca^{2+} and anions like Cl^- and SO_4^{2-}. Therefore, the objectives of the present study were: (i) to determine the influence of both NaCl and Na_2SO_4 concentrations and composition on K^+, Ca^{2+} and Mg^{2+} uptake by Fajr genotypes during seedling stage and (ii) to examine the relationships between Na^+/K^+, Na^+/Ca^{2+} and Na^+/Mg^{2+} and growth characteristics of the rice seedlings under salinity condition.

Materials and method

One cultivar of irrigated land (Japonica group) rice (*Oryza sativa* L.), cv. Fajr is salt-tolerant and was selected from Rice Research Institute of Iran. Rice seeds were hydroponically grown for 21 days by half strength modified Hoagland's nutrient solution as control (pH=5.7±0.2 and EC=1±0.1 dS/m). Salinity treatments have been created at the concentrations of 3, 5 and 7 dS/m. Each concentration level was prepared by NaCl, Na_2SO_4 and their mixtures in the ratios of 1:1, 2:1 and 1:2 molar concentrations. The roots of rice seedlings were scanned by WINRHIZO system (chemistry lab, Land Resource Management Department, UPM). Subsequently, for mineral nutrient analysis (Ca^{2+}, Mg^{2+}, K^+ and Na^+) as described by Sahrawat *et al.* (2002), Five hundred mg of samples (root or shoot part) were ashed using a muffle furnace for 6 hours at 550 °C. Concentrated HCl and HNO_3 (20%) were added to ash and heated for 1 hour. The mixture was decanted to a 25 ml volumetric flask and washed from the beaker with distilled water. The solution was analyzed for K^+, Ca^{2+}, Mg^{2+} and Na^+ by inductively coupled argon-plasma emission spectrometry (ICP trace analyzer; Land Resource Management department, University Putra Malaysia).. Differences between individual means were identified using Tukey's range test at the 5% significance level.

Results

The data analysis from scanned roots showed that the root length was only affected by salinity stress. The root length decreased when salinity level increased. Fajr genotype demonstrated the different shoot height and dry biomass when salt stress was created by different salt compositions. The tallest and the shortest shoot height were observed at NaCl and 1:1 molar ratio, respectively (Figures 1 and 2). Water content of root was not affected by salt concentration, while a significant difference in water content of shoot was observed under salinity condition. The water content of shoot decreased when 2:1 molar ratio as salt treatment was applied (Figure 3). After salt stress for 21 days, Fajr genotype showed a very large increase in Na^+ content in both shoot and root compared to control. The Na^+ and K^+ concentrations were increased by raising the salinity level. However the Na^+/K^+ ratio was maintained in both shoot and root under salinity condition (Figure 4). Na^+/K^+ ratio in both shoot and root tissue did not show significant difference when salt composition was changed. Na^+/Ca^{2+} ratio of root tissue decreased when Cl^- concentration dominated in root medium. However salt treatment with SO_4^{2-} dominance caused an increase of Mg^{2+} content in root tissue. This result was similar to the study of Mor and Manchanda (1992). Ca^{2+} concentration of root tissue decreased up to 7 dS/m, but salinity stress significantly increased magnesium concentration of root cells up to 5 dS/m.

The root characteristics such as root length, root surface area, root volume, tips and fork were not significantly influenced by salt composition. The Fajr genotype had different shoot dry biomass as the salt composition was changed. The highest and the lowest dry biomass were recorded for NaCl at 5 dS/m and 1:1 molar concentration ratio at 7 dS/m, respectively. The most reduction of shoot height was observed for mixtures of NaCl and Na_2SO_4 (1:1, 1:2 and 2:1 molar ratios). The K^+ amount in shoot tissue was more at 1:2 molar ratio than other salt compositions. Ca^{2+} content of root tissue was reduced at 1:2 molar ratio less than for other salt compositions, but the maximum amount of Ca^{2+} was observed at 2:1 molar ratio (Figure 5). The elements were transferred from root to shoot cells at 1:2 molar ratio more than for other salt compositions. Significant correlations between Na^+/K^+, Na^+/Ca^{2+} or Na^+/Mg^{2+} and growth parameters were not observed.

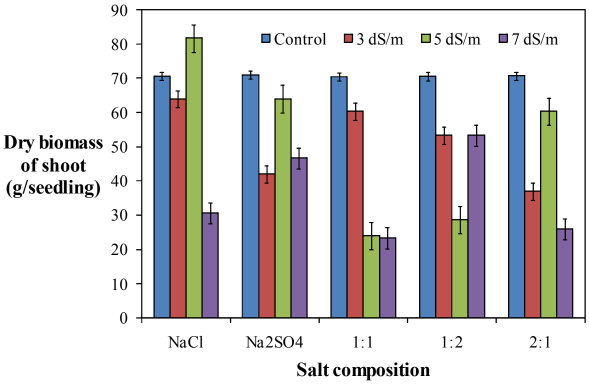

Figure 1. Fajr genotypebiomass differently responded to salt compositions. Vertical bars represent ±SE.

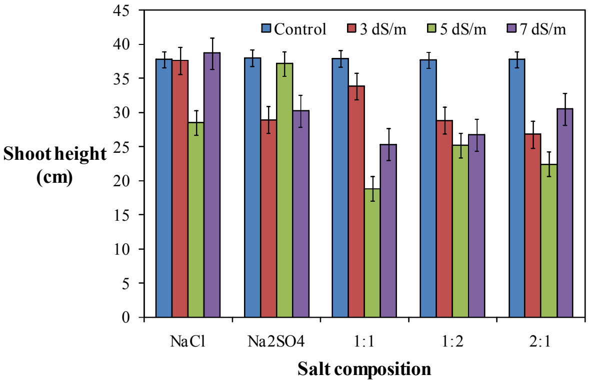

Figure 2. Shoot height at different salt compositions and salt levels. Vertical bars represent ±SE.

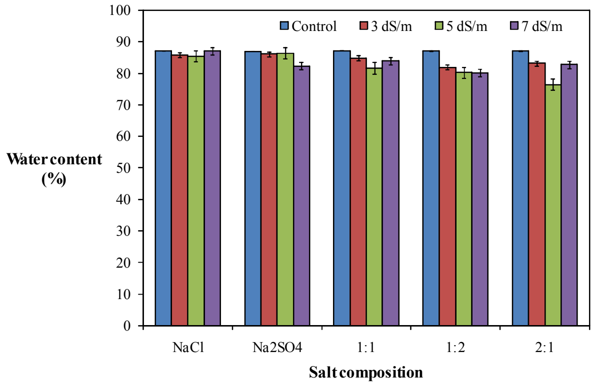

Figure 3. Water content of shoots depended upon salt composition and concentration. Vertical bars represent ±SE.

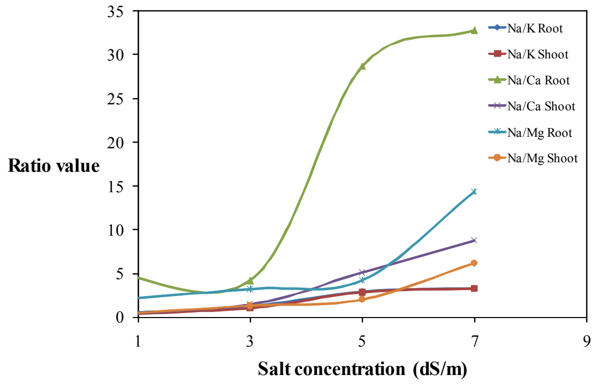

Figure 4. Increasing salt concentration increased the element ratio in both shoot and root.

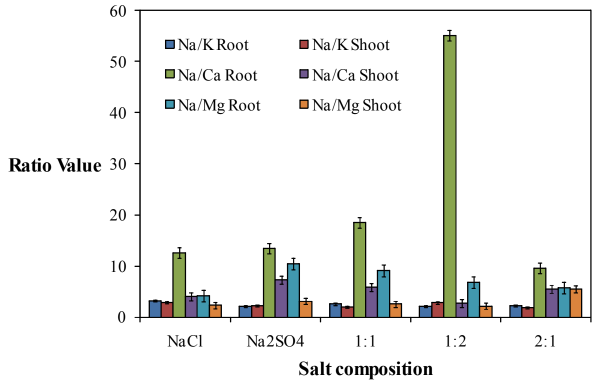

Figure 5. Nutrient ratios in shoot and root were changed by different salt composition. Vertical bars represent ±SE.

Conclusion

The reaction of the salt tolerant Fajr genotype to salt compositions showed extreme variability with salt composition. It seems that salt concentration has more effect on root growth than shoot growth (Munns 2002). Fajr genotype apparently had the lowest Ca^{2+} uptake from nutrient solution when chloride-sulfate (with sulfate dominance) solution was applied. It seems that SO_4^{2-} has an antagonistic effect on Ca^{2+} uptake. It is concluded that Na^+ accumulated in shoot can be deleterious but K^+, Ca^{2+} and Mg^{2+} accumulation compensate for Na toxicity. A careful consideration of cation concentrations in shoots indicated that there is a gradual increase in Na^+ while K^+, Ca^{2+} and Mg^{2+} remained almost constant with salinity levels up to 5 dS/m. It is assumed that the composition of sodium salts play a role in cationic balance within the Fajr genotype. Mineral nutrients imbalance in salt stressed plants is due to interaction between anions (SO_4^{2-} and Cl^-) and nutrients. This interaction was intensified when the salt compositions were 1:1, 1:2 and 2:1 molar ratios. Therefore the degree of salt tolerance during rice growth for different sodium salt compositions may not always be the same.

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Managing soil surface salinity with subsurface drip irrigation

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Abstract
The classical 'leaching requirement' approach for salinity management does not work well with subsurface drip irrigation (SDI), because irrigation with SDI results in no leaching above the depth of the drip tape, and salts will accumulate throughout the growing season. Irrigation with SDI can maintain suitable root-zone salinity, but surface salt accumulation will occur unless there is adequate leaching due to rainfall or supplemental surface irrigation. Facilitating crop establishment with SDI will help to improve the long-term economic sustainability of SDI. Our research has shown that, in arid-region soils irrigated with SDI, very high soil salinity can occur at the soil surface. This can inhibit germination of small seeded, salt-sensitive crops. Growers have several options for managing salinity with SDI: 1) supplemental leaching using sprinklers or flood irrigation, 2) transplanting, and 3) bed shaping to allow planting into soil of low salinity. The most appropriate method will depend on equipment, the crop to be planted, and other factors. In climates with >450 mm of annual rainfall, leaching from rainfall will probably be sufficient to maintain soil salinity below harmful concentrations with SDI.

Introduction
Drip irrigation is the application of water under low pressure through low-flow emitters embedded within the walls of plastic tubing. In the U.S.A., surface drip irrigation is reserved mostly for permanent (e.g. tree) crops, while subsurface drip irrigation (abbreviated herein as SDI) is used widely for annual crops. Modern SDI installations can last for 20 years or more with proper maintenance. When compared to surface irrigation (flood and furrow), SDI may reduce water loss to evaporation, deep percolation, and completely eliminate surface runoff (Phene 1990). The use of SDI may also increase crop marketable yield and quality (Ayers *et al* 1999). The use of SDI can result in high nutrient use efficiency (Thompson *et al* 2002). Saline irrigation water can be used with SDI, while maintaining yields and improving water use efficiency compared to surface irrigation (Cahn and Ajwa 2005, Siefert *et al* 1975, Tingwu *et al* 2003), because SDI can result in suitable root-zone salinity (Hanson *et al* 2009).

Accumulation of salts in concentrations detrimental to plant growth is a constant threat in irrigated crop production. With surface irrigation, leaching adequate amounts of water through the soil profile (e.g. the 'leaching requirement') is the desired method for maintaining suitable soil salinity. However, the classical 'leaching requirement' approach does not work well with SDI (Hanson *et al* 2009), because irrigation with SDI results in no leaching above the depth of the drip tape, and salts will continue to accumulate throughout the growing season (Dasberg and Or 1999; Hanson and Bendixen 1995; Oron *et al* 1999). The amount of salts that will accumulate above the drip tape is a function of several factors, including, but not limited to, water quality (Ayers *et al* 1993) and evapotranspiration (Burt *et al* 2003). Salt accumulation with SDI is of particular concern in arid and semi-arid regions, where high rates of evapotranspiration and low rainfall can result in large amounts of salt accumulation near the soil surface. This salt can hinder production of salt-sensitive crops.

Salts that accumulate near the soil surface become particularly important when SDI-irrigated fields are replanted. The most obvious way to avoid crop failure or yield reduction due to poor stand establishment is by leaching salts from the surface to a depth where they no longer pose a threat to seedlings (Hanson and Bendixen 1995; Hanson 2003). Sprinkler irrigation is the most commonly used method of leaching salts below the drip tape. Using sprinkler irrigation for germination in fields with SDI is effective but requires high capital inputs (Hillel 2000) above that required for installation and management of the permanent SDI system. The need for frequent use of sprinklers can threaten the long-term economic sustainability of SDI. Less than 10% of producers using SDI in California rely solely on SDI for crop establishment (Burt and Styles 1994). Farms in the arid southwest, USA may grow two crops per year. Reducing use of sprinklers could reduce costs of production and result in more acreage converted to SDI.

Researchers have investigated SDI tape depth and its resulting effect on yield following establishment (Charlesworth and Muirhead 2003; Lamm and Trooien 2005). This research focused on the availability and plant uptake of water and nutrients, but did not address effects of tape depth on salt accumulation and crop emergence. Oron *et al*. (1999) showed that salt accumulation near the soil surface depended on water quality and tape depth. They also showed that tape depth affects where salts accumulate by changing the location of the wetted perimeter. Cook *et al*. (2003) and Thorburn *et al*. (2003) showed that the wetted area with SDI (radius of wetted perimeter, wetted distance above the drip tape and wetted distance below the drip tape) is a function of texture and soil hydraulic properties. They showed that soil hydraulic properties control the wetted distance above the drip tape; however tape depth controls the amount of water that reaches the surface and the resulting salt accumulation.

Subsurface drip irrigation is a valuable irrigation method in arid and semi-arid regions. However, little research has been reported that evaluates effects of salinity on establishment of crops with SDI in successive seasons. Developing alternatives to reduce or eliminate the need for sprinklers during crop establishment will help to improve the long-term economic sustainability of SDI. Thus, we initiated a field experiment in Arizona to determine effects of tape depth, water quality, and germination method on salt accumulation and germination of successive crops.

We evaluated the effects of tape depth (18 and 25 cm), irrigation water salinity (ECw), (1.5 and 2.6 dS/m) and germination method (SDI vs. sprinkler) on end-of-season salt distribution with SDI during two growing seasons (Roberts *et al* 2008). We intensively sampled the planted area at the end of two growing seasons. Following season 1, in which we planted cantaloupe (*Cucumis melo cantalupensis*), salt accumulation was high enough to significantly reduce the germination and establishment of the next crop. Sprinklers were needed to achieve 100% establishment of direct-seeded broccoli (*Brassica olearacea* L. *Italica*) during season 2. Areas with exceptionally good water quality (<0.5 dS/m) may not require sprinkler pre-irrigation for several years, as shown by Burt *et al*. (2003). Where water cost is low and water quality is sufficiently high, the use of SDI for germination and establishment may be preferred. However, if water cost or salinity is high, use of sprinklers for pre-irrigation may be preferred, because less water is needed for germination. The cost and quality of water available to growers will influence which irrigation procedures are used during germination and establishment of small seeded, salt sensitive crops.

Conclusions

Methods for managing salt with SDI include using sprinklers, transplanting, and bed shaping. Using transplants would eliminate the need for sprinklers during establishment, because the root ball is usually placed a few cm below the zone of highest salt accumulation. However, sprinklers are often used with transplants to prevent desiccation, because several hours may be required for water to move from the drip tape to the root zone. Transplants may eliminate the need for sprinklers to manage salts, but require high capital inputs and may not improve the economic sustainability of SDI. Bed shaping has been use as a means to manage salt accumulation above the drip tape. This method involves forming the beds to a peak and pre-irrigating to move salts toward the peak. The tops of the bed are then removed into the furrow leaving behind soil of low ECe. Direct seeding of some large-seeded crops can then occur without concern of inhibited emergence. Small seeded crops that require precision planters cannot usually be direct-seeded into moist beds. Bed shaping procedures may prove effective in some crop rotations by eliminating the need for sprinklers, but the excess water needed to pre-irrigate beds may be less economically feasible, depending on water cost. In climates with >450 mm of annual rainfall, leaching from rainfall will probably be sufficient to maintain soil salinity below harmful concentrations, except when very saline irrigation water is used.

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Microbial activity and dissolved organic matter dynamics in the soils are affected by salinity and sodicity

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Abstract
A laboratory incubation experiment was conducted to assess changes in microbial activity, dissolved organic matter (DOM) and nutrients dynamics in response to salinity and sodicity. We hypothesised that salinity would decrease microbial activity due to osmotic stress, whereas sodicity would increase microbial activity as a result of increased organic matter solubility. A non-saline non-sodic soil was repeatedly leached using a combination of 1M NaCl and 1M $CaCl_2$ solutions to reach $EC_{1:5}$ 0.4, 1.2, 2.5 and 4.0 dS/m combined with SAR < 3, 10 and 20. Two percent finely ground wheat straw residue was added as an amendment. The results indicate that cumulative respiration on day 64 was more strongly affected by EC than SAR. Cumulative respiration was highest at low $EC_{1:5}$ (0.4) and high SAR (20) and lowest at high $EC_{1:5}$ (4.0) and high SAR (20). Increasing salinity adversely affected the microbial activity in the soil, whereas increased the microbial activity in response to sodicity was only observed at $EC_{1:5}$ (0.4).

Key Words
Microbial activity, dissolved organic matter, salinity, sodicity.

Introduction
High concentrations of salt in soils constraint crop production and have enormous influence on soil organic matter (SOM) content. Salinity has been found to negatively influence the size and activity of soil microbial biomass and biochemical processes essential for maintenance of soil organic matter (Rietz and Haynes 2003; Tripathi *et al.* 2006). Sodicity, i.e. a high percentage of Na on the adsorption sites, can lead to increased SOM solubility and thus loss of C and N (Peinemann *et al*. 2005) from soils. Dissolved organic matter (DOM) is the most mobile and dynamic non-living organic matter fraction. It comprises only a small part of soil organic matter (< 1 % of soil organic C); nevertheless, it is a primary source of mineralizable C, N and P and affects many processes in soil such as nutrient translocation and leaching (Qualls and Haines 1991), microbial activity, mineral weathering and plant nutrient availability (Kuiters and Mulder 1993). Leaching of DOM can reduce the amount of DOM available for microbial mineralization and therefore, may influence soil nutrient cycling and soil fertility. In spite of the extent of salt affected soils in Australia, studies on the magnitude and mechanisms of changes in dissolved organic matter dynamics in these degraded environments are fragmentary. DOM losses in salt affected soils are expected to be high due to solubilization of organic matter in sodic soils and decreased microbial activity in saline soils. The aim of the present experiment was to study the effect of salinity and sodicity and their combination on microbial activity, dissolved organic matter and nutrient dynamics in soil.

Materials and Methods
A non-saline and non-sodic sandy soil (95% sand, 1.3% silt and 3.7% clay, pH (1:5) 6.5, 49 mg/kg organic carbon was collected from Monarto located 80 km east of Adelaide in South Australia. The area experiences hot, dry summers and mild winters with the mean annual rainfall of 352 mm. The soil was thoroughly mixed to ensure uniformity, air dried, sieved to 2mm and stored at room temperature.

Soil preparation
Twelve salt solutions of known EC and SAR were prepared using a combination of 1M NaCl and 1M $CaCl_2$. The soil was leached repeatedly with these solutions to achieve $EC_{1:5}$ 0.4, 1.2, 2.5 and 4.0 dS/m combined with SAR < 3, 10 and 20. These EC values were chosen because previous experiments in our group (unpublished data) had shown that soil respiration was not affected at $EC_{1:5}$ <1 and negligible above $EC_{1:5}$ >4. Soils with SAR <3 are non-sodic, soils with SAR 10 are considered to be sodic according to the Australian soil classification system (Isbell 1998), whereas soils with SAR >13 are considered sodic in most other countries (Soil survey staff 1999). After adjustment of EC and SAR, the soils were air-dried.

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Incubation
Before the start of the experiment, the soil water content of the prepared soils was adjusted to 85 % water holding capacity (WHC) which in this soil is optimal for microbial activity, and kept at 25°C for 10 days in the dark before amendment with residues. This is done to avoid the flush of activity that occurs after rewetting at the start of the experiment since this could mask the treatment effects. After the preincubation, wheat straw (C: N ratio 120:1), ground and sieved to 0.25-2 mm, was thoroughly mixed into the soil. Twenty five grams of soil with residues were placed into polyvinyl cores fitted with a nylon mesh at the bottom was and then transferred into individual incubation jars. Respiration was quantified by measuring headspace CO_2 concentrations using a Servomex 1450 infra-red gas analyser (Servomex, UK) at different intervals. Samples were harvested at different times during the 90 days experiment and analysed for microbial biomass, DOM (DOC, DON and DOP), SUVA, inorganic N, EC, SAR and pH.

Results and discussion
Since the experiment is still in progress at the time of the writing of the manuscript, only soil respiration data up to day 64 is shown here. On day 64, cumulative respiration was highest in the low-salinity and high sodicity (EC 0.4, SAR 20) treatment, whereas it was lowest in the high-salinity and high sodicity (EC 4.0, SAR 20) treatment (Examples for EC 0.4 and 4.0 are shown in Figure 1a, b). Cumulative respiration on day 64 was more strongly affected by EC than SAR. It decreased by 43-59% as EC values increased from 0.4 to 4.0, whereas SAR 20 increased cumulative respiration by 8% and 1.5% at EC 0.4 and 1.2, respectively (Figure 2) However, at EC 2.5 and 4.0, there was no increase in cumulative respiration with increasing SAR. The differences in cumulative respiration among various treatments became more evident after 28days.

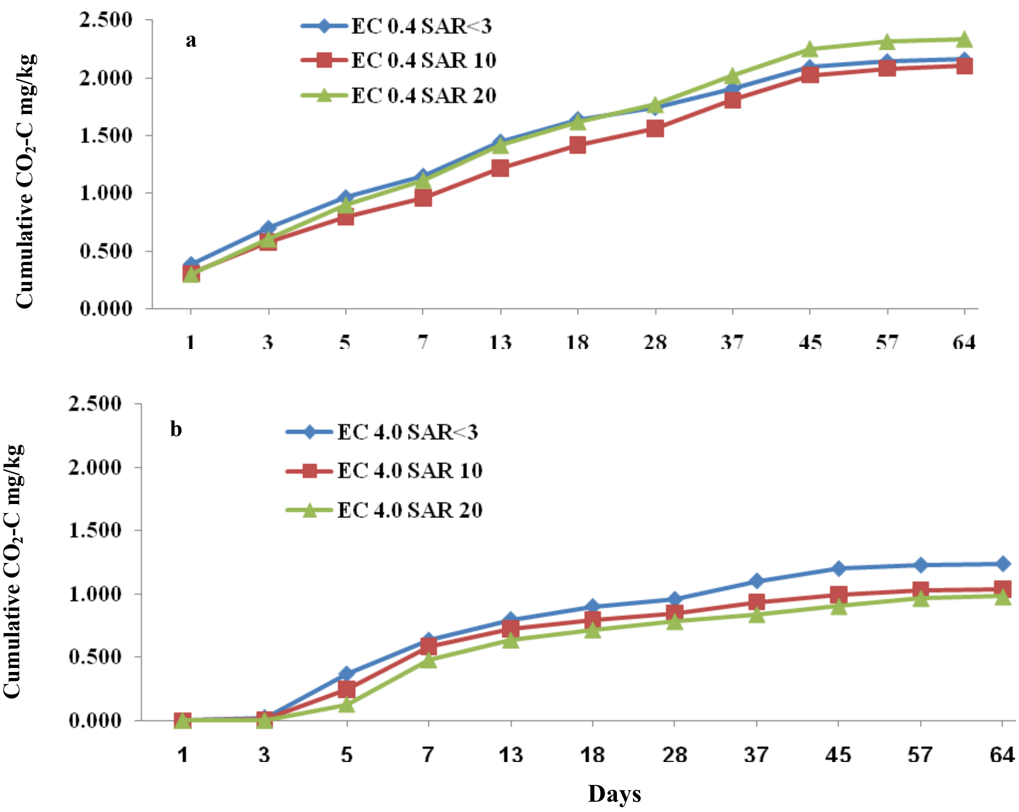

Figure 1. Cumulative respiration with increasing SAR at EC 0.4 (a) and EC 4.0 (b).

Increasing salinity causes an increase the osmotic potential in the soil adversely affecting the microbial activity, whereas high SAR results in increased organic matter solubility; thus, the increase in the soil microbial activity at high-sodicity and low-salinity (EC 0.4, SAR 20) can be explained by solubilisation of soil organic matter which provided additional substrate for decomposition by microbes. This pattern is similar to what was found by Nelson *et al.* (1996) in laboratory incubation study. Jandl and Sollins (1997) have also suggested that soluble carbon can provide a large proportion of the microbial substrate. The lack of effect of high SAR on respiration at higher EC can be explained by the flocculation caused by high EC which counteracts the increased solubility induced by high SAR.

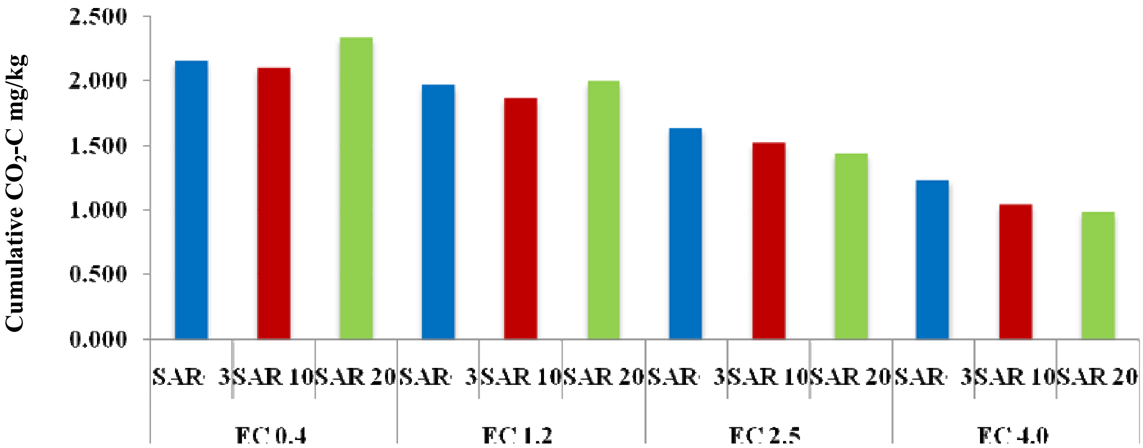

Figure 2. Cumulative respiration on day 64 at EC 0.4, 1.2, 2.5 and EC 4.0 in combination with SAR <3, 10, 20.

Conclusions

Increasing salinity adversely affects the microbial activity in the soil, whereas the effect of sodicity was only observed at $EC_{1:5}$ (0.4) where it increased the microbial activity in the soil. Further analysis of the soil samples harvested at different intervals is in progress to assess the effects of EC and SAR on microbial biomass, dissolved organic carbon, nitrogen, phosphorous and nutrients.

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Root Zone WSB Model: towards a framework for the sustainable application of saline effluent on land.

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Abstract
The sustainability of a system for land disposal of saline effluent is fundamentally dependent on whether salt concentrations in the soil can be maintained at levels that allow adequate plant growth to remove water, salt or other undesirable solutes. Hence a suitably high leaching fraction is required to limit salt accumulation. If other undesirable solutes are present, the excessive amount of water application may give rise to other environmental problems of excessive solute accumulation or discharge. A framework is required to balance these opposing requirements for a sustainable land disposal system. A simple and robust Root Zone WSB (Water and salt balance) model has been developed on an excel spreadsheet that can accurately predict the deep drainage and salt concentrations in the root zone. This model has been successfully applied to land disposal sites for non-saline and saline industrial effluents in Queensland and results show reasonably accurate prediction of deep drainage and salt concentration in the root zone over a 4 year period.

Key words
Saline land disposal, effluent irrigation, water balance, salt balance, deep drainage.

Introduction
Industrial cities produce large volumes of effluent waste, and often this waste is discharged into waterways creating a health hazard. Land application of the effluent can be a viable alternative which keeps waterways clear from toxic chemicals. The effectiveness of land application of effluent depends on both plant and soil properties. The presence of vegetation is essential to assist the removal of water through transpiration. Where the effluent is saline, it is also essential that the soil maintains sufficiently high hydraulic conductivities to allow adequate leaching and limits salt accumulation in the root zone.
The application of saline effluent on land is governed by two material balances in the following order of priority (So *et al.* 2004):

1) The water balance of the root zone where the input of water equals the output of water, or

$$P + I = ET + \Delta W + RO + DD \qquad [1]$$

where: P = precipitation (mm), I = irrigation (mm),
ET = evapo-transpiration (mm), RO = run-off (mm),
ΔW = change in soil water storage (mm), DD = deep drainage (mm).

1) The salt balance of the root zone where salt input equals salt output, or

$$D_iC_i + S_m = D_dC_d + S_p + S_{pl} \qquad [2]$$

where D_i and D_d are the depth of irrigation and drainage water,
C_i and C_d are concentrations of irrigation and drainage water,

S_m, S_p and S_{pl} are the amount of salt dissolved from soil minerals, precipitated in the soil and removed during plant harvest respectively. The parameters S_m, S_p and S_{pl} are generally small and negligible, thus reducing the salt balance to:

$$D_iC_i = D_dC_d \qquad [3]$$

These steady state equations are approximately correct for sufficiently long periods of observations where climatic extremes are absent. It assumes uniform conditions throughout the root zone, and the term DD in equation 1 is equivalent to the term D_i in equation 2 and 3. Clearly, the real situation is that salt concentration will be lowest at the surface (C_i) and increases towards the bottom of the root zone (C_d), except for the immediate surface soil.

Where the groundwater is sufficiently shallow, some salt will accumulate at the immediate surface due to evaporation. The pattern of increase in salt concentration with depth depends on the removal rate of water, which is determined by the rate of evapo-transpiration of the vegetation. The salt balance may not apply to conditions where the combination of distribution of rainfall and soil are such that it leads to short periods of high leaching, e.g. sandy soils with short periods of intense rainstorms.

The interactions between these processes are dominated by the water balance where the DD component becomes the determining factor for the degree of salt accumulation in the root zone or any other compound. As the sustainability of a saline land disposal system is fundamentally dependent on whether salt concentrations in the soil can be maintained at levels that allow adequate plant growth to remove water (ET), salt (S_{pl}) or other solutes, a suitable leaching fraction will be required to limit salt accumulation to desired levels.

If the fate of other nutrients are of interest within this system, it can readily be added as a third material balance such as a nitrogen balance. However this will not be disc used in this paper.

Computer models which can predict water and salinity levels can be useful in the management of these processes. This paper describes a root zone water and solute balance (Root Zone WSB) model which can be used to accurately estimate the amount of deep drainage and salt concentration of the root zone under a saline land disposal system. This model can be used as a framework to develop sustainable land disposal systems or evaluate the sustainability of such systems.

The Root Zone WSB Model.

The Root Zone WSB model is based on the water balance equation [1] with the salt balance equation superimposed within each layer. It is developed as an Excel spreadsheet model with the input and outputs managed using macros written in visual basic.

The model assumes vertical heterogeneity in the soil by considering soil horizons or layers with uniform soil properties. The current model allows up to 5 horizons, but can readily be modified to any desired number of layers. These layers are treated in a cascade pattern where the DD from the layer above is taken as the input into the layer below. Evapotranspiration is divided into Evaporation from the bare soil (layer 1 only) and the Transpiration from the plants. Water extraction from the lower soil layers is considered as occurring only as transpiration. The contribution from each of the soil layers to the total transpiration is considered as proportional to the distribution of effective water absorbing roots in that layer, not total roots present. Calculations were conducted with a daily time step.

Figure 1 shows the flow diagram of the processes employed in the model. The available water in layer 1 is calculated from the initial water content in that layer with inputs/outputs of evapotranspiration, rainfall, irrigation and runoff. Following rainfall or irrigation, evapotranspiration is split into evaporation from soil and transpiration based on the vegetation cover. Evaporation is assumed to be a linear function of the available water level in the soil. The water content of the soil, calculated in the above step, is then used to modify evaporation from layer 1. Transpiration is allocated to each soil layer based on the proportion of active roots in each layer. These modified evaporation and transpiration are then combined to give the actual ET for layer 1. This value is then used in step 1 to recalculate the available water and the associated deep drainage when it occurs. This deep drainage becomes the input to the next soil layer. The water removal from these deeper layers are treated as occurring only through deep drainage and transpiration, with each layer contributing an amount of transpiration proportional to its effective rooting density.

The salinity in each of the layers is calculated from the salinity of irrigation water, modified by appropriate dilutions or concentration due to the recharge in each of the soil layers. The salinity of the water moving from one layer to the next is considered to be the salinity of the saturated soil extract of the layer above.

The model was validated against measured deep drainage and root zone salinity on land disposal systems with effluent irrigation under two different scenarios. Locations of both of these projects were close to the city of Brisbane. In project 1, Mahogany trees were grown under different Nitrogen levels with a grass plot as the control, with domestic effluent of low salinity levels (Edraki 2002). Components of the water balance of these plots were monitored over a period of 22 months. The deep drainage values in each of these plots were measured. In project 2, saline effluent irrigation was applied to grassland of about 50 ha continuously for over 5 years and the levels of salinity in each of the soil layers were monitored over most of this period. (So *et al.* 2003)

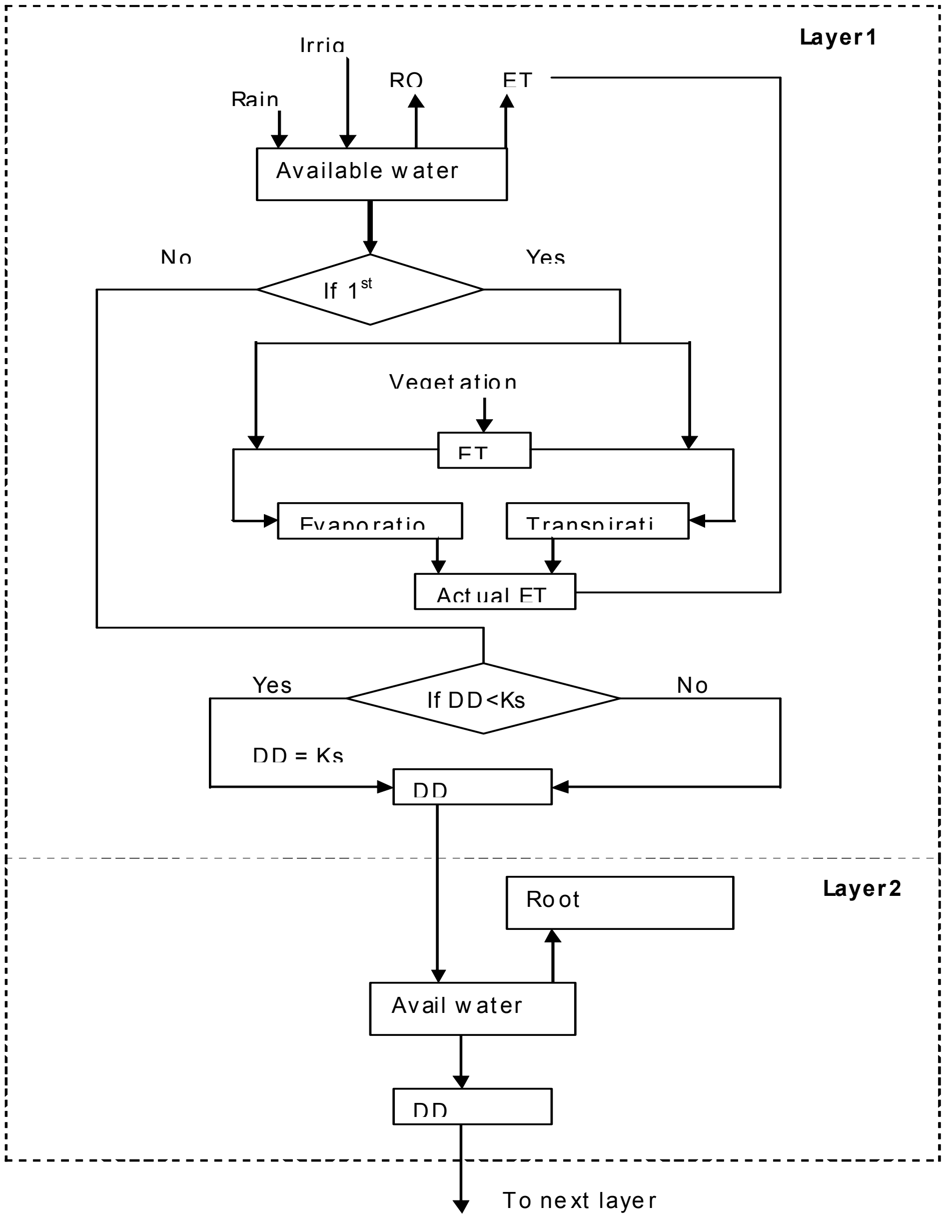

Figure 1. A flow diagram of the processes employed in the Root Zone WSB model.
DD= deep drainage; ET= Evapotranspiration; RO= Run-off; K_S= Saturated Hydraulic Conductivity.

Results

The deep drainage values predicted with the model and the measured values are shown in Figure 2. The model predictions agree well with the measured deep drainage values.
Overall the predicted values of total deep drainage over the period of monitoring (22 months) agrees well with the total measured values of deep drainage. There were a few outliers and in particular plot 4 (triangle in Figure 2 which was not included in the regression) where the predicted value was significantly below the measured values. The reasons for these are not clear as the experimental data were collected several years prior to this work.
In project 2, monitoring of soil water and soil salinity was conducted from 2000 to 2003. Inputs were daily rainfall and irrigation over this period, and the initial soil water content and soil salinity in January 2000. Soil water content profiles were regularly monitored with a neutron probe, and soil salinity levels were monitored annually. Simulation was conducted using 3 soil horizons (0-30 cm; 30-80 cm and 80-180 cm depths) with a daily time step. Effective root distributions were derived from two soil water content profiles in January 2000. The results of predicted salt concentrations in the 3 soil horizons at 1, 2 and 3 years of irrigation and rainfall are presented in Figure 3.

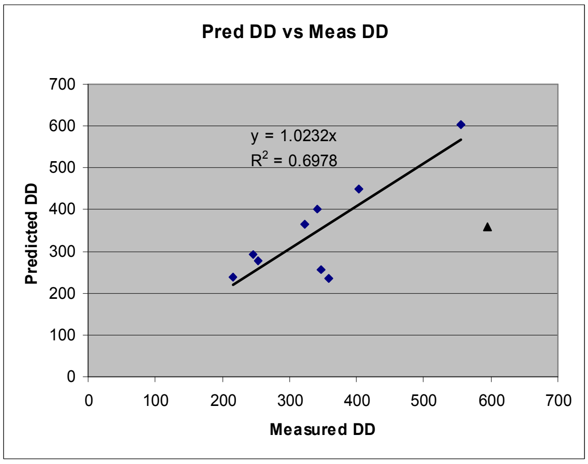

Figure 2. Plot of predicted DD and measured DD from project 1. Plot 3 (Δ) is an outlier and was not included in the regression.

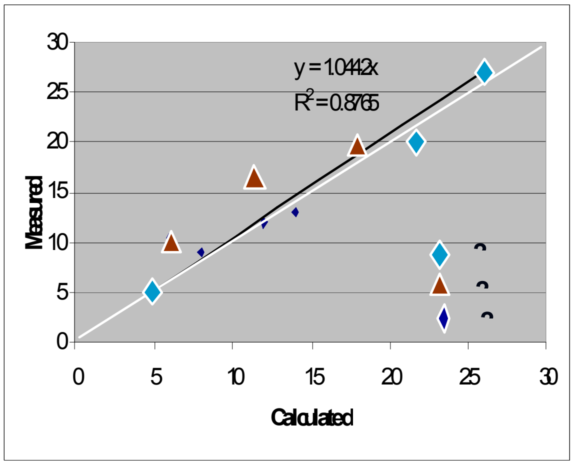

Figure 3. Predicted salt concentrations in 3 soil horizons plotted against measured salt concentration in project 2. Initial soil water contents, salt concentrations and root distribution were determined in January 2000. Data were for 2001 (◇), 2002 (▲) and 2003 (◆).

At this stage, only total amounts of DD and EC within the root zone has been predicted with reasonable accuracy (slope approximately equal to one, with an R^2 of 0.7 for DD and 0.88 for EC). At no stage of the simulation were parameters adjusted to fit the data, all parameters used were measured parameters. The simplicity and the minimal amount of data required make this approach useful for the end-user. The model can readily be enhanced by the inclusion of a third material balance e.g. NO_3.

In **conclusion**, we have shown that a simplistic water balance model of the root zone with minimal inputs and soil layers can potentially be developed as a useful tool for the development and management of sustainable land disposal systems for saline effluent.

Acknowledgement

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SALTIRSOIL: A simple integrated simulation model for the prediction of soil salinisation in agricultural irrigated well-drained lands

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Abstract
SALTIRSOIL (SALTs in Irrigation SOILs) is a soil salinisation model able to make accurate predictions of soil salinity, sodicity and alkalinity at soil water saturation using no more information than that obtained during most regular land surveys. It is a deterministic, static and functional (capacity-type) process-based model composed in turn of two main modules. The first one calculates the soil water balance through the year, and hence the soil solution concentration factor with regard to the irrigation water. Next, the irrigation water major ion composition is multiplied by this factor and then, the second module, called SALSOLCHEM, calculates the major inorganic ion composition of the soil solution at equilibrium with soil calcite and gypsum at the soil CO_2 partial pressure. The SALTIRSOIL algorithms were verified by simulating two horticultural crop developments in a fine to medium texture heavily calcareous soil under a semi-arid Mediterranean climate. The quotients of electrical conductivity at saturation to electrical conductivity in the irrigation water were 1.68 and 1.60 respectively. These quotients of EC_{25} are very close to the value of 1.5 used in the development of FAO guidelines for irrigation water assessment.

Key Words
Soil salinisation, agricultural modelling, irrigation, SALTIRSOIL model.

Introduction
When waters are applied to soils for irrigation, the salts they carry in solution are also applied. Crops absorb water and exclude the major portion of salts, which are left behind in the soil. The absorbed water is transpired to the atmosphere and therefore salts concentrate in the soil solution. However, when part of the irrigation water percolates through the bottom of the rooting depth, the salt build-up in soils does not increase indefinitely, it naturally reaches an equilibrium point. This equilibrium point features a steady state, in which the mass of salts entering the soil equals the mass of salts leaving it. With the water table under control or deep enough, the salt concentration in the equilibrium point depends on the irrigation water salinity as well as on climate (evapotranspiration and rainfall) and irrigation water amounts, being independent from groundwater depth and salinity.
The guidelines for water quality classification for irrigation purposes are often specified as 2D-plots where the salinization and sodication risks are jointly evaluated graphing the electrical conductivity at 25ºC (EC_{25}) and the sodium adsorption ratio (SAR) on the the *x* and *y* axes respectively. The guidelines are the summary of models able to predict the salinization and sodication of soils assumming average climate and conditions of use. Ayers and Westcott (1985) based the FAO guidelines on a model which gave as a result that the saturation extract concentrates 1.5 times regarding the irrigation water. This condition is expressed by equation 1 where $\overline{C_{\mathrm{SE}}}$ is the average salt concentration of the soil water at saturation and C_{I} is the salt concentration of the irrigation water.

$$f_{\mathrm{SE}} = \frac{\overline{C_{\mathrm{SE}}}}{C_{\mathrm{I}}} = 1.5 \qquad (1)$$

However, wherever climate, soil and management conditions significantly different from those under which the guidelines were derived are met, they should be changed.
The aims of this work are to outline the model conceptualization, development and verification of algorithms, and computer implementation of a new easy-to-use low-data-demanding model called SALTIRSOIL designed to predict the average electrical conductivity and composition of salts in the mid to long term in the soil solution of irrigated well-drained lands.

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Model development

Model conceptualization of SALTIRSOIL

SALTIRSOIL (Visconti *et al* 2006; Visconti 2009) is a deterministic, static and functional (capacity-type) process-based model which calculates the major inorganic ion composition and electrical conductivity at 25ºC in the soil solution at water saturation. Specifically, SALTIRSOIL is composed of two primary modules (Figure 1).

Module A calculates the soil water balance and as a consequence the relative concentration of the soil solution at field capacity with regard to the irrigation water. This variable, called the concentration factor at field capacity (f_{FC}), is an average value calculated from the soil surface to the specific soil depth chosen by the user. Provided the soil water content at field capacity and at saturation are known, the concentration factor at saturation is calculated (f_{SE}). The concentrations of the major inorganic ions in the irrigation water are multiplied by the concentration factor at saturation. The concentrations obtained from this calculation are used to feed a chemical equilibrium module called SALSOLCHEM (SALine SOLution CHEMistry). SALSOLCHEM calculates the major inorganic ion concentrations at equilibrium in the soil solution. Finally, the electrical conductivity at 25 ºC is calculated from this composition using the equation developed by Visconti (2009).

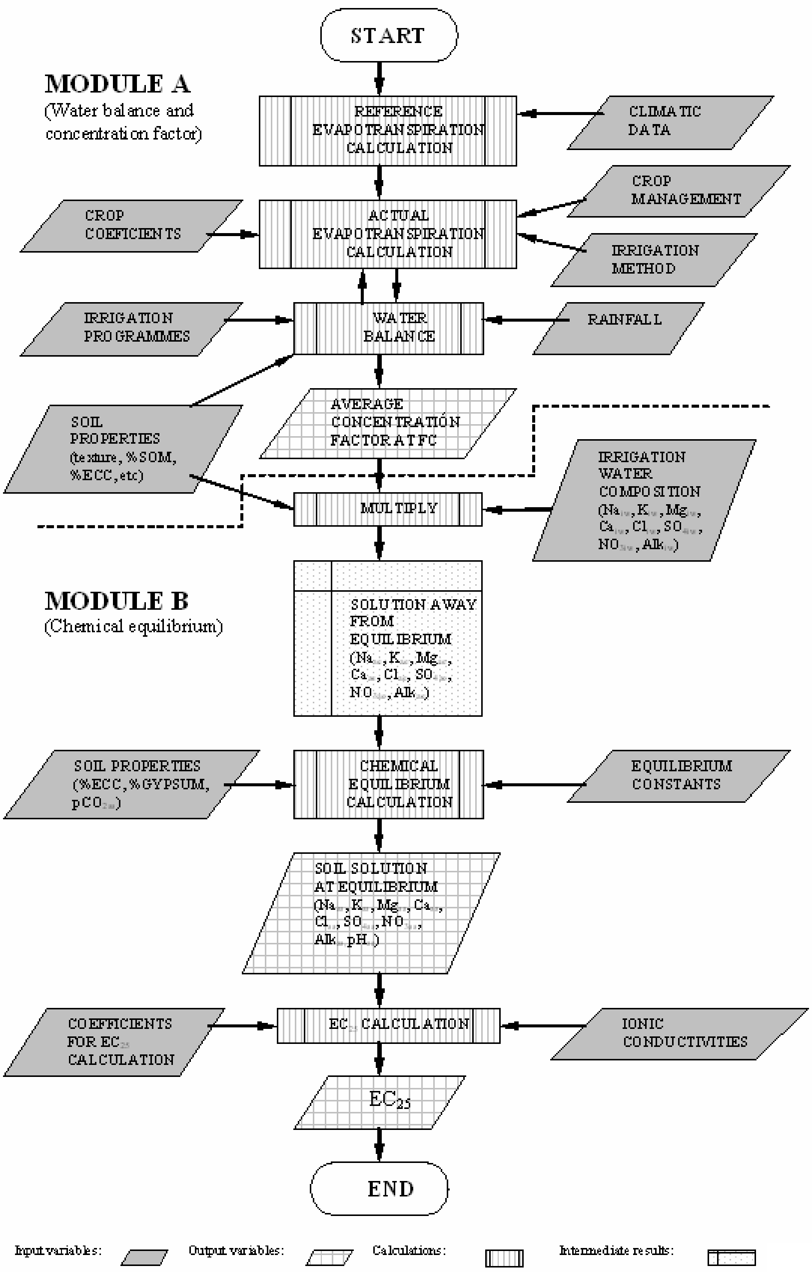

Figure 1. Flowchart of SALTIRSOIL.

Soil solution concentration factor and electrical conductivity

The average relative concentration of a conservative solute with regard to the irrigation water at field capacity (f_{FC}) can be calculated by means of equation 2, and at saturation by means of equation 2 and 3. Equation 2, where I and R stand for the annual irrigation and rainfall amounts, ET_j for the evapotranspiration from layer j, and n for the number of layers, has been obtained taking the approach that the concentration factor of each soil layer is equal to the concentration factor of the drainage water from that layer, and then calculating the mean concentration factor of the n soil layers in which the soil has been formally split. As the number of soil layers increases, this assumption is more reasonable. In equation 3 θ_{gFC} and θ_{gSE} stand for the gravimetric water content at field capacity and saturation respectively.

$$f_{FC} = \frac{\overline{C_{FC}}}{C_I} = \frac{I}{n}\sum_{i=1}^{n}\frac{1}{I + R - \sum_{j=1}^{i} ET_j} \quad (2) \qquad f_{SE} = \frac{\theta_{gFC}}{\theta_{gSE}} f_{FC} \quad (3)$$

The electrical conductivity of the soil solution in SALTIRSOIL is calculated from the major inorganic ion concentrations according to equation 4 (Visconti 2009).

$$EC_{25} / \mathrm{dS\,m^{-1}} = \left[0.21 + 0.681\left(\sum_{i=1}^{n} |z_i| \lambda_i^0 [i]\right)\right] \pm 0.28 \qquad (4)$$

Where $|z_i|$ is the charge of ion i in absolute value in units of $mmol_C$/mmol, $[i]$ is the free ion concentration of ion i in units of mmol /L, and λ_i^0 is the ionic conductivity at the limit of infinite dilution of ion i in units of S $cm^2/mmol_C$.

Computer implementation

SALTIRSOIL has been written in Visual Basic 6.0© in a modular way. The climatic, irrigation, crop and soil data are stored in several sheets within a Microsoft Excel© workbook with a predetermined structure, which can be read by SALTIRSOIL. The reference evapotranspiration is calculated first, then the crop evapotranspiration and then the water balance, which is used to calculate the actual crop evapotranspiration afresh. This calculation is repeated until convergence is reached. Once the terms of the water balance are known, the average concentration factor at field capacity is calculated by means of equation 2. Knowing the soil water content at field capacity and at saturation, the concentration factor at this water content is also calculated with equation 3. The major ion concentrations in the irrigation water are multiplied by the concentration factor of interest, and the major ion concentrations at equilibrium with calcite, gypsum and CO_2 are calculated with the chemical equilibrium module SALSOLCHEM. SALTIRSOIL reads the values of the thermodynamic equilibrium constants from a sheet within the same Microsoft Excel© workbook. Finally the electrical conductivity at 25 ºC is also calculated by means of equation 4 using the apropriate data stored in another sheet within the Excel© workbook.

In SALTIRSOIL, an easy-to-use graphical user interface (GUI) has been designed with which the user controls the running of the simulations.

Results and discussion

Water balance and calculation of the soil solution concentration factor

SALTIRSOIL was applied to the calculation of the water balance and soil solution concentration factor at field capacity and at saturation. Two simulations were carried out with. Simulation 1 is the growing of a sweet melon crop, and simulation 2 is the consecutive growing of two crops: sweet melon and potato. A fine to medium texture heavily calcareous soil under a semi-arid Mediterranean climate was used. In both simulations the soil was split in 64 discrete layers.

The concentration factor of salts in the soil solution at field capacity (f_{FC}) in simulation 1 is equal to 3.10, which is higher than in simulation 2, in which is 2.83 (Table 1). This fact is shown on the concentration factor at saturation, which is 1.85 in the simulation 1 and 1.69 in simulation 2 (Table 1). The soil solution concentration factor at field capacity provided by a leaching fraction of 0.15-0.20 can be assumed to be equal to 3 according to Ayers and Westcot (1985). This value is bracketed by those found in our simulations. Nevertheless, the resulting concentration factors at saturation (in the saturation extract) in our simulations though similar, are significantly higher than the value given by Ayers and Westcot (1985), which is 1.5.

Major ion composition and electrical conductivity
Simulations 1 and 2 were finished including the irrigation water quality to calculate the major ion composition and electrical conductivity of the saturation extract (Table 2). The equilibrium constants and other data are given in Visconti (2009). An apparent CO_2 partial pressure equal to $10^{-3.07}$ atm for the saturated paste was also used.

Table 1. Summary of simulations 1and 2.

variable	Simulation 1	Simulation 2
Rainfall / mm /year	255	255
Irrigation / mm /year	400	520
ET_a / mm /year	558	631
Drainage / mm /year	98	144
ET_a / ET_c	0,82	0,88
$D/(R + P)$	0,15	0,19
f_{FC}	3,10	2,83
f_{SE}	1,85	1,69

Table 2. Average soil solution composition* in the saturation extract except the pH, for which the value in the saturated paste was calculated.

Simulation	Na	K	Ca	Mg	Cl	NO_3	SO_4	Alk	pH_{sp}	EC_{25}	EC_{se}/EC_{iw}
1	27,0	0,7	17,6	9,3	24,4	0,4	21,8	1,04	7,78	5,43	1,68
2	24,6	0,7	17,4	8,5	22,3	0,4	21,3	1,02	7,77	5,16	1,60

*All ion concentrations in mmol /L, Alk in $mmol_C$ /L and EC_{25} in dS /m.

The average electrical conductivity of the saturation extract in simulation 1 was 5.4 dS /m, whereas in simulation 2 was 5.2 dS /m. The quotient of electrical conductivity of the saturation extract to the irrigation water (EC_{se}/EC_{iw}) is equal to 1.68 in simulation 1 and 1.60 in simulation 2. Both values are lower than the respective salt concentration factors (Table 1, bottom row). The quotients EC_{se}/EC_{iw} are closer than the concentration factors to the value of 1.5 used by Ayers and Westcot (1985) to develop the FAO guidelines.

Conclusions

Two horticultural crop developments in a fine-to-medium texture heavily calcareous soil, under a semi-arid Mediterranean climate were simulated with SALTIRSOIL. Both simulations gave similar soil solution concentration factors at saturation with regard to the irrigation water. The quotients of electrical conductivity at saturation to electrical conductivity in the irrigation water were somewhat higher but very similar to the value of 1.5 used in the development of FAO guidelines for irrigation water assessment.

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Season-long Changes in Infiltration Rates Associated with Irrigation Water Sodicity and pH

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Abstract
There is increasing need to substitute low quality waters, including saline sodic waters and treated municipal waste water for fresh water when irrigating land in arid and semi-arid regions of the world. In almost all instances low quality waters are more sodic than the fresh waters currently utilized. A major hazard associated with these waters is the reduction in water infiltration rates due to the increase in the soil exchangeable sodium percentage. Deterioration of soil; physical properties may threaten the present and future productivity of these lands. We examine the effect of even small increases in sodium on the infiltration rate over the span of a complete cropping season in a series of experiments from sodium adsorption ratio (SAR) of 0-13. Based on these controlled studies with wetting and drying cycles over 180 d conducted in container studies, we conclude that for the non-calcareous soil examined, even small increases in SAR resulted in significant decreases in infiltration rates. The deterioration in infiltration capability increased with time, suggesting that short term experiments may not characterize the long term consequences of using degraded waters for irrigation. Increased pH resulted in decreased infiltration at comparable SAR values.

Key Words
Infiltration soil, sodicity, pH, irrigation.

Introduction
Decreasing availability of fresh water in arid and semi arid lands means that in order to sustain irrigation in these regions we will need to utilize lower quality waters. Use of more saline and more sodic (higher SAR) waters will result in increased soil salinity and exchangeable sodium. Many low quality waters available for irrigation, such as treated municipal waste water, also have elevated alkalinity and pH. Use of these waters for irrigation will result in increased soil pH as well as increased exchangeable sodium. In well drained soils, if there is sufficient fresh water available, salts can be periodically leached and amendments can be applied to reduce exchangeable sodium and lower pH. The major hazard in terms of soil properties is not the change in chemical properties per see but rather the impact of those changes on the soil physical properties, such as hydraulic conductivity, soil strength etc.

Water quality criteria have been primarily based on guidelines such as Ayers and Westcot (1985). In turn these guidelines were developed from field observations and short term laboratory experiments that measured hydraulic conductivity under saturated water flow and changing solution composition, such as McNeal *et al.*(1966, 1969), Frenkel *et al.* (1978). Also, current water suitability guidelines do not consider the effect of pH. Suarez *et al.* (1984) determined that elevated pH adversely impacted saturated hydraulic conductivity in laboratory column experiments with applied waters at SAR 20 and SAR 40. Classification of a soil as sodic, generally regarded as exchangeable sodium percentage of 15% or greater, was developed to describe soils that were clearly adversely impacted. One difficulty with visual observations is that important deterioration of soil physical properties is not always evident. The column experiments have provided a very useful database but prediction has been difficult due to the very large differences among soils relative to their stability under sodic conditions (Pratt and Suarez (1990). In addition, column studies may not be representative of field conditions in that they do not consider wetting and drying, surface impacts, and long term effects. In order to better evaluate the SAR effects, we have conducted experiments over a season interval with wetting and drying and in the presence and absence of rain.

Methods
Pachappa (fine sandy loam soil), was collected, air dried, and crushed to pass a 5-mm screen. We utilized plastics containers of 35.50 cm height and 28 cm diameter. We added 1 cm of fine quartz sand (No. 90) to

the bottom of the containers, then horizontally placed two ceramic extractors (1 bar air entry value) into the sand, then added an additional 7 cm of sand. The soil was packed into the container (20 cm of soil) at a bulk density of 1.30 Mg/m^3. Containers were placed in an outdoor area under a rainfall simulator using a randomized design. There were 12 water treatments and three repetitions. The rain machine is a traveling sprinkler system with an overlapping spray pattern with rain drop diameter of 1.8 mm. The details of the rainfall simulator are available in Suarez *et al.* (2006). An additional set of containers with soil were placed at an adjacent location outside the rain machine. These containers receive only irrigation water, again with 12 treatments and three replications.

The simulated rain consisted of water with an EC of 0.016 dS/m. The 12 different water compositions were prepared with variation of the value of SAR (0, 1, 2, 3, 5, 7, 5, 10 and 13) and two values of pH (7.0 and 8.2). The pH differences were achieved by substituting some of the Cl^- ions with HCO_3^-. Waters were prepared and stored in 240 L containers. Tap water (EC = 0.6 dS/m and SAR < 0.4 $mmol^{1/2}/ L^{1/2}$) was initially applied to enable soil settling before the start of the treatments. Containers with more than 5% deviation from the mean infiltration rate were removed and the containers were repacked. The soil under the rain simulator was subject to an initial rain event in order to establish the starting infiltration rates before application of the treatment irrigation waters. After this rain event and subsequent drying, the first irrigation water treatments were initiated. The experiment under the rain simulator consisted of alternate rain and irrigation events with drying between water applications, for a period of six months (2005-2006).

For the irrigation water experiment only irrigation water was applied with drying between irrigations. A pressure of -50 kPa (0.5 bars), was applied to the extractors, before, during and after the application of the water but it was suspended once drainage flow ceased. An irrigation event consisted of an application of 5 cm depth of water. Infiltration times were recorded for the applied depth of water to infiltrate into the soil surface. After irrigation the soil was allowed to dry and another event was initiated after tensiometers in two adjacent control soil containers registered values of -33 kPa or lower.

Results

The initial infiltration rates with irrigation water at pH 7.0 were at 68 ± cm/d, as shown in Figure 1. These initial variations were not significantly different. The infiltration rate of the SAR 0 treatments decreased only slightly, over the 180 d of irrigation and drying cycles. The very first incremental increase in SAR (to SAR 1) resulted in a slight but significant decrease in the infiltration rate relative to the control, SAR 0 treatment, as can be seen in Figure 1.

Increasing SAR of the irrigation water resulted in a decreasing infiltration rate at all times. The greater the increase in SAR, the greater was the decrease in the infiltration rate. Based on these data shown in Figure 1 we conclude that for a noncalcareous soil, any increase in SAR results in a corresponding decrease in infiltration rate. Comparable experiments with 2 calcareous soils from the Northern Great Plains (Suarez *et al.* 2006) showed statistically different rates at SAR above either 4 or 6, however those experiments had much greater experimental variation within the treatments and thus less ability to distinguish difference among treatments. Also, those experiments did not have SAR 1 and SAR 3 treatments, thus the present experiment was better able to define infiltration changes at low SAR.

Further examining the data in Figure 1 it is observed that the SAR impacted the time dependence of the infiltration rate. The greater the SAR, the more pronounced was the rate decrease with time. For example at SAR 13 the rate after 170 d was approximately 50% of the rate after 20 d, while for SAR 2 the final rate was only reduced by 8% when compared to the rate after 20 d. This suggests that short term experiments will underestimate the extent to which SAR impacts infiltration, especially with increasing SAR.

Additional experiments conducted were conducted with this container system using waters of pH 8.2 and comparable SAR and irrigation water compositions and experimental methodology. In this instance the infiltration rates were lower than those reported above at the same SAR values at pH 7.0, suggesting that even a small increase in the pH also contributed to a loss in the soil infiltration rate.

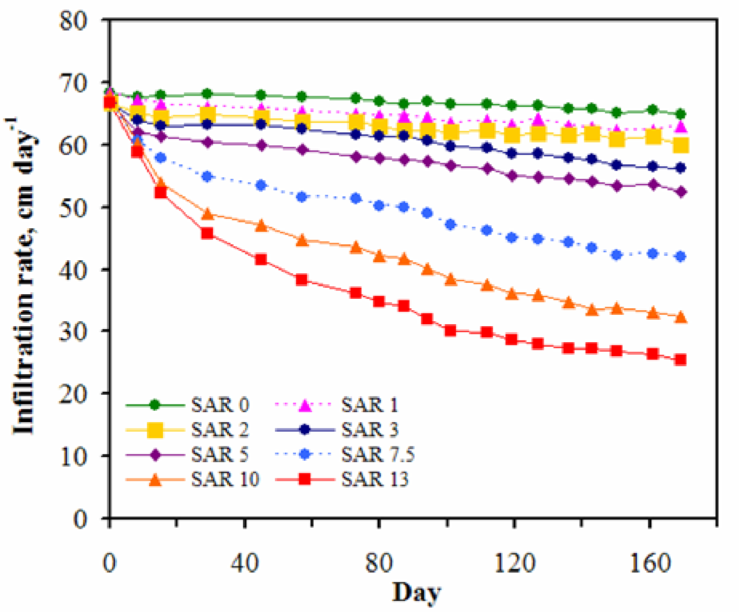

Figure 1. infiltration rate as a function of time and SAR of the irrigation water for treatments at pH 7.0 and irrigation with wetting and drying cycles.

Conclusion

The consequences of reduced soil productivity associated with irrigation with low quality water are very severe. At present there is uncertainty about the utility of existing guidelines. There are large differences in the response of different soils in hydraulic conductivity of laboratory saturated columns of soils reacted with sodic waters. The current results indicate that soils are affected by even small increases in SAR and that season-long studies of infiltration show much larger reductions in infiltration than that observed over limited times and in column studies of saturated hydraulic conductivity. Until the guidelines can be applied with confidence, the impact of sodic waters on soil properties and productivity can best be evaluated with season-long studies with wetting and drying cycles.

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Using EM38 to assess the progress and mechanism of salt leaching from tsunami affected soil in Aceh, Indonesia

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Abstract
A portable electromagnetic induction instrument (EM38) was used in both the horizontal (EMh) and the vertical (EMv) dipole orientations, to monitor changes in soil salinity in the tsunami affected areas of Aceh. The relative changes EMh and EMv over time were used to assess leaching progress and mechanism in both lowland irrigated and rainfed rice fields, and rainfed palawija (dry season crops) fields.
Time series data from EM38 surveys indicated that leaching of salts from the tsunami affected soil occurred slowly by both vertical displacement and horizontal movement in flood waters. However, the vertical leaching was more restricted due to the presence of a claypan layer in the lowland rice fields. Faster removal of salts should be facilitated by providing adequate surface drainage and irrigation channels to allow good water circulation.

Key Words
Sea water inundation; apparent electrical conductivity; salt; ECa.

Introduction
The Indian Ocean tsunami in December 2004 salinised and damaged agricultural soil in low-lying coastal areas around the Indian Ocean (Chaudhary *et al.* 2006; Rengalakshmi *et al.* 2007; Chandrasekharan *et al.* 2008; Raja *et al*. 2009), and damaged irrigation, drainage and road infrastructures. After the tsunami, farmers in Aceh reported crop failure, prompting the need to monitor the changes in soil salinity and to find ways to increase the leaching of salts out of farmlands.

Field instruments for measuring the apparent electrical conductivity (ECa) of soils using electromagnetic induction (EM) have been widely used to assess soil salinity. A portable ground-based EM instruments such as the EM38 (Geonics Pty Ltd) can provide a rapid measure of ECa to a maximum depth of 1.5 m. The ground placement of the EM38 determines the shape of the primary electromagnetic field emitted from the instrument into the soil. This determines the zone of sensitivity of the measurement in the soil profile. When the instrument is placed on the ground horizontally, the primary field (EMh) is strongest at the soil surface and declining with depth, while the primary field for the vertical placement (EMv) is strongest at 0.35 m depth and declining in sensitivity to a depth of 1.5 m (McNeil 1980). Slavich (2002) suggested that the average of profile ECa or (EMh+EMv)/2 provides a better representation of the root zone salinity compared to the value of EMh or EMv alone, and the relative value between EMh and EMv can be used to estimate the distribution of soil salinity in the soil profile. If the measurement is conducted over time, the relative values of EMv and EMh can be used to assess the salt leaching mechanism. This could guide management to enhance salt leaching from agriculture soils that are salinised due to tsunamis or cyclones.

Leaching of surface salts can occur either by horizontal movement as a result of surface flooding and movement of water or through vertical displacement of salts by water percolating and draining through the root zone. Figure 1 represents a simplified model of vertical leaching of salt leaching after seawater inundation (Slavich *et al*. 2006). It was assumed that shortly after the tsunami, the soil salinity of the affected areas was highest near the surface soil. Therefore at this stage EMh is expected to be greater than EMv (leaching progress stage 1). This assumption is based on: (1) the December 2004 tsunami occurred in the middle of the wet season and the soils were likely to have been close to or at saturation; (2) most soils in the tsunami affected areas area are used for lowland paddy which contain a dense claypan at about 0.2 m below the surface; and (3) sediment deposited at the soil surface would have had a high concentration of salt. High soil moisture and the presence of the impermeable claypan layer are likely to restrict deep percolation of sea water.

The vertical leaching of surface salt should cause a decrease in soil salinity at shallow depths (decrease in EMh) and a corresponding increase in subsoil salinity (increase in EMv), and lower average profile ECa.

This assumes there is potential for vertical drainage and that no further salinisation occurs at the soil surface. During lateral movement of salts from the surface soil by flood waters, subsoil salinity would be expected to change very little. Therefore, under this process EMh readings would be expected to decrease and EMv would either not change or decrease slightly, so that the average ECa would decrease.

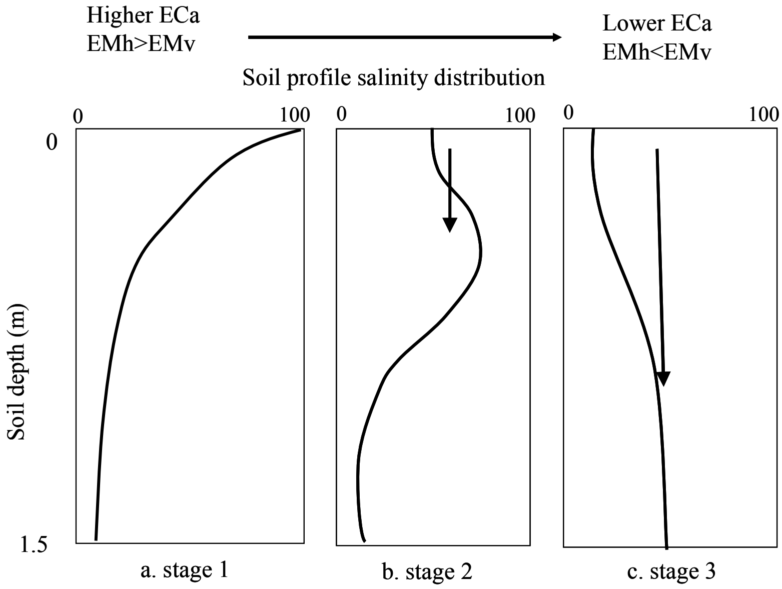

Figure 2. A conceptual model of soil profile salinity distribution and leaching after seawater inundation, with dissolved salts moving through the soil profile. Stage 1 shortly after seawater inundation (EMh > EMv); stage 2 after some leaching (EMh = EMv), and stage 3 after advanced leaching (EMh < EMv)

Methods

After the tsunami, agricultural research and extension staff in Aceh were trained in the use of EM38 to measure soil salinity levels (Figure 2). The first survey of tsunami affected sites was conducted in August 2005. Twenty three monitoring sites with a good field agriculture extension support were selected. Five EM38 measurements were conducted on these sites between August 2005 and December 2007. In each site, 1-3 fixed transects of up to 100 m each were selected based on visual assessment of crop performance (poor, medium, and good). The soil ECa was measured in both the horizontal (EMh) and the vertical (EMv) dipole orientations, at about 5 m intervals along each transect. Changes in EMh and EMv values of transects over time were used to infer stages of leaching based on Figure 1 and the direction of leaching.

Figure 3. Training of agricultural research staff in Aceh to use the EM38 instrument (left), using EM38 in a vertical dipole orientation (middle), and using the EM38 instrument in a horizontal dipole orientation (right)

Results and discussion

Leaching status based on the conceptual model (Figure 1) for each site through time (Table. 1) suggested that in August 2005, 15 of the 23 sites had been subjected to some degree of leaching (Stage 2 or 3). The number of sites at these stages of leaching was unchanged through to May 2006. The number of sites at stage 3 leaching increased to 17 sites only by January 2007 and to 21 sites by December 2007. Most of the changes in EM38 time series data were between stage 1 and stage 3 leaching. Stage 2 leaching was not detected very often and was only observed at site 16 in August 2005. This could have resulted because the time where EMh = EMv might have occurred between measurement times.

Table 2. Stage of leaching at each site from August 2005 to December 2007. S-1, S-2, and S-3 represent stages of leaching described in Figure 1.

Site	Aug-05	Jan-06	May-06	Jan-07	Dec-07
1	S-1	S-3	S-3	S-3	S-3
2	S-3	S-1	S-1	S-1	S-3
3	S-3	S-3	S-1	S-3	S-3
4	S-3	S-3	S-3	NA	NA
5	S-1	S-1	S-1	S-3	S-3
6	S-3	S-3	S-3	S-3	S-3
7	S-3	S-1	S-1	S-3	S-3
8	S-3	S-1	S-1	S-1	S-3
9	S-3	S-1	S-1	S-3	S-3
10	S-3	S-3	S-3	S-3	S-3
11	S-1	S-1	S-3	S-3	S-3
12	S-3	S-3	S-3	S-3	S-3
13	S-3	S-1	S-3	S-3	S-3
14	S-3	S-3	S-3	S-3	S-3
15	S-3	S-3	S-3	S-3	S-3
16	S-2	S-3	S-3	S-3	S-3
17	S-1	S-1	S-1	S-1	S-3
18	S-1	S-3	S-3	S-3	S-3
19	S-3	S-3	S-1	S-1	S-1
20	S-1	S-1	S-1	S-1	S-3
21	S-1	S-3	S-3	S-3	S-3
22	S-1	S-3	S-3	S-3	S-3
23	S-3	S-3	S-3	S-3	S-3

Leaching of salts was slow and was also likely to have been affected by the redistribution of salts during flooding events. The leaching status of 4 out of 8 sites that were at stage 1 leaching in August 2005, remained unchanged in January 2006, and only progressed to stage 3 leaching by December 2007. However, there were also five sites (2, 6, 7, 8, 12) that were already at stage 3 leaching in August 2005, but reverted back to stage 1 leaching in January 2006, before progressively being leached again. This might have been due to the severe flooding across these sites in December 2005, redistributing salts, so that the salinity of some sites increased, while some decreased. By the end of 2007 most of these sites were leached, except site 19 that was surrounded by a housing development blocking the drainage outlet.

The relative changes and value of EMv and EMh for the three main landuse systems across the assessment sites are presented in Figure 3. The salinity level at the rainfed rice field (Figure 3. middle) was much higher than the palawija (Figure 3 left) and the irrigated rice fields (Figure 3 right). This is because the rainfed rice fields do not have irrigation and drainage channels so the seawater was trapped for longer periods of time compared to the irrigated rice and palawija fields. In the rainfed palawija site, the EMh was slightly greater than EMv in August 2005, and by January 2006, EMh had decreased and EMv had increased. This suggests that vertical leaching of salts has occurred. In the rainfed rice field there was a large increase in EMh, but with a much smaller increase in EMv in May 2006, which suggests horizontal redistribution of salts. Both EMh and EMv then progressively decreased from May 2006 to the end of 2007, possibly due to a combination of vertical and horizontal leaching processes. The heavy rain from September to December 2005 and the flooding in December 2005 might have contributed to this.

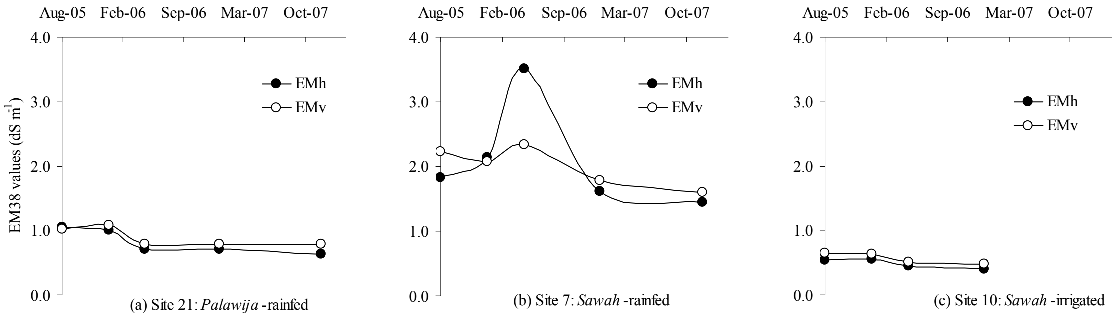

Figure 4. Changes in EMh and EMv over time in sites with different land use systems.

The impermeable claypan layers in the lowland rice fields are likely to have reduced the depth of infiltration of sea water and limited the rate of vertical leaching, so the reduction in salinity level is likely to have been by surface movement with irrigation or flood waters.

Conclusion

This study indicates that EM38 can be used to evaluate leaching progress and mechanism in tsunami affected soils. Leaching of salts occurred slowly by both vertical displacement and horizontal movement in flood waters. Given the low permeability of Aceh's lowland agriculture soils and the presence of the claypan layer in rice fields, the removal of salts from salt affected lowland rice fields should be conducted through horizontal flushing by providing a good drainage and irrigation infrastructure.

Acknowledgements

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Validation of SALTIRSOIL for the calculation of salt composition and electrical conductivity in horticultural soils

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Abstract
A validation exercise of the SALTIRSOIl model developed to predict average major ion content, pH and electrical conductivity in soils under risk of salinisation, has been carried out in two irrigated horticultural subplots cropped to water melon and pepper . Calculated values were compared with depth-averaged measurements made in saturated pastes from soil samples taken at three soil depths during the growing season of 2008. SALTIRSOIL predicts reasonably well ion composition, pH and electrical conductivity of saturation extracts in these studied horticultural soils irrigated by surface systems. Nevertheless, in order to carry out a more complete validation, more plots and crop species are necessary.

Key Words
Soil salinisation, ion composition, agricultural modelling, irrigation, SALTIRSOIL model

Introduction
Coastal alluvial soils for horticultural crops under surface irrigation systems in the Valencian Community (Eastern Spain) are under risk of salinisation due to several factors such as intense evapotranspiration, scarcity and loss of quality of the irrigation water, over-irrigation, water-logging, misuse of fertilizers and management practices. At the same time, irrigated agriculture is also depleting and polluting water supplies in many places. Ideally, it would be desirable to know the concentrations of the individual solutes in the soil water without the intensive soil sampling and laboratory analyses necessary for characterizing the salinity conditions of extensive areas. SALTIRSOIL (Visconti 2009) is a capacity-type, steady-state and chemical equilibrium model developed to predict average major ion content (sodium, calcium, magnesium, chloride, sulphate, etc) in the medium to long term in productive well drained soils.
Our objectives in this study were i) to calculate the composition of the average soil solution in the saturated paste from two furrow irrigated plots cropped to water melon and pepper in an area under risk of salinisation in Mediterranean Spain and ii) to compare the calculated values with those observed.

Methods
Study area and experimental plots
Two experimental subplots were selected in the lower *Palància* river basin in Valencian Community, Mediterranean coast of Spain. Climate is characterised by high evapotranspiration (1000 mm/yr) and low rainfall (less than 500 mm/yr). Soils near the coast are fine-textured and coarser inland. Irrigation in horticultural soils is applied by both surface and drip systems. Irrigation water quality in the area varies from good (1 dS/m) to salty (4 dS/m). The experimental area (1.3 ha) has been cultivated to produce vegetables for many years. It has been monitored since late spring 2007 until early autumn 2008. Soil texture is clay loam (USDA), medium in organic matter and calcium carbonate. During 2008 it was cropped to water melon (subplot 1, 1ha) and pepper (subplot 2, 0.3 ha), and furrow irrigated with salty water (4.2 dS/m) from a nearby well.

Plot sampling and soil analyses
Each experimental subplot was sampled monthly from April until November 2008 at two points, one near the irrigation water inlet (point 1), and another one opposite this in the direction of the water flow (point 2). At each point and date, soil was sampled at three depths: 0-10, 10-30 and 30-60 cm. Eighty-four soil samples were analysed in the saturated paste for main inorganic ion composition, pH and EC_{25}.
Saturated soil-pastes were prepared adding deionised water to the soil according to the method described by Rhoades (1996) with no addition of sodium hexametaphosphate solution in the saturation extract. Soil saturation extracts were analysed for electrical conductivity (EC_{25}), sodium, potassium, calcium, magnesium, sulphate, chloride, nitrate, alkalinity and pH. Determination of EC_{25}, pH, and alkalinity were performed within 2 hours of extract collection. Simultaneously, an aliquot of the soil saturation extract was diluted with

deionised water. Ions were determined by ion chromatography in the diluted extracts filtered through 0.45 μm pore filters to remove particulate material, within 4 days of extract collection. EC_{25} was measured with a Crison microCM 2201 conductivity meter with temperature probe. The pH was measured with a Crison GLP22 pHmeter. Alkalinity was determined by potentiometric titration with sulphuric acid 10 mM standardized every week.

Simulations

Simulations of the soil saturated-extract composition in the experimental plot were carried out with the weather, water, irrigation, crop, soil and chemical information shown in boxes 1 and 2. The information used to calculate the soil solution concentration factor (Visconti 2009) is shown in box 1, and so is in box 2 the information used to calculate the final composition in equilibrium with CO_2, calcite and gypsum.

Box 1. Input information to calculate soil solution composition

Weather from Benavites station:

- ❖ Rainfall of 501 mm/yr
- ❖ Reference evapotranspiration of 1022 mm/yr calculated according to Penman-Monteith (Allen *et al.* 1998)

Irrigation

- ❖ Programme:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mm	0	0	0	80	0	30	23	92	123	0	0	0
days	0	0	0	1	0	1	1	4	6	0	0	0

- ❖ Water quality:

EC_{25}	Na	K	Ca	Mg	Cl	NO_3	SO_4	Alk	pH
4.23	14.7	0.3	8.0	6.8	24.8	4.1	6.4	3.8	7.95

All ions in mmol/L, Alk in meq/L and EC_{25} in dS/m

Crop:

- ❖ Species: subplot 1 water melon (*Citrullus lanatus* L.) with cabbage foot, and subplot 2 pepper (*Capsicum annuum* L.)
- ❖ Basal crop coefficients (Allen *et al.* 1998):
  - ➢ Water melon

Stage	initial	development	mid season	late season
Duration / days	32	45	45	31
Crop coefficient	0.15	0.55	0.95	0.83

  - ➢ Pepper

Stage	initial	development	mid season	late season
Duration / days	34	34	35	30
Crop coefficient	0.15	0.63	1.10	0.80

- ❖ Growing season: water melon from 26th April till 6th September, and pepper from 14th May till 3rd September
- ❖ Maximum shaded soil: 47% water melon and 42% pepper
- ❖ Maximum rooting depth: 60 cm
- ❖ Water extraction pattern: 40-30-20-10

Soil:

- ❖ Physical properties
  - ➢ Stone percentage: < 5%
  - ➢ Texture (USDA): 35-43 and 33-38 clay-sand in point 1 and 2 respectively
- ❖ Chemical properties
  - ➢ Equivalent calcium carbonate: 14%
  - ➢ Gypsum: < 0.5%
  - ➢ SOM: ~ 3% in the 10 surface cm

Drainage:

- ❖ Pipeline 60 cm deep with a 9 m spacing

During the growing season, three irrigation water samples were taken and analysed with the same methods used for the soil extracts.

Texture, soil organic matter and equivalent calcium carbonate were determined according to the Spanish Ministry of Agriculture official methods (MAPA 1994).

A weighted average soil saturation-extract composition was calculated for each of the two points using equation 1 where P is the average value of the property and $P_{0\text{-}10}$ is its value in the sample from the 0-10 soil layer and so is $P_{10\text{-}30}$ from the 10-30 layer, etc.

$$P = (P_{0\text{-}10} + 2\,P_{10\text{-}30} + 3\,P_{30\text{-}60})/6 \qquad (1)$$

Water contents at saturation and field capacity were calculated with pedotransfer functions developed for agricultural soils of Valencian Community (Visconti 2009).

Box 2. Input information to the chemical equilibrium calculation

Chemical equilibrium constants:

- ❖ Ion association constants: Lindsay (1979)
- ❖ Calcite solubility product (pKs): 8,29.
- ❖ Gypsum solubility product (pKs): 4,62.

CO_2 partial pressure in equilibrium with the solution in the soil saturated paste after 4 hours: $9.5\ 10^{-4}$ atm

Results

Subplot 1 water melon

The soil composition of the saturation extract in points 1 and 2 calculated with SALTIRSOIL (Sim1-1 and Sim1-2 respectively) was compared to the corresponding measured compositions (Figure 1). The calculated values of electrical conductivity in the saturation extract (EC_{se}) in point 1 (3.24 dS/m) and point 2 (3.29 dS/m) differed only in 0.05 meq/L. This is a negligible difference, as the only important input variable different between both points is the sand fraction, which is an order of magnitude less important than the electrical conductivity of the irrigation water (EC_{iw}) on EC_{se} calculation as we know from the Sensibility Analysis (Visconti 2009). For the two points, the measured EC_{se} are 5.17 and 3.51 dS/m, respectively. The EC_{se} point is observed under the 1:1 line in Sim1-1 (left scatter plot), and on the 1:1 line in Sim1-2 (centre scatter plot). The error in the calculation of EC_{se} in Sim1-1 is because the errors in the calculation of chloride, sodium, calcium, magnesium and sulphate, which are, in this order, the most abundant ions in the irrigation water. These ions make up the major portion of salts in the irrigation water, and in the soil solution also, and then dominate the calculated value of electrical conductivity.

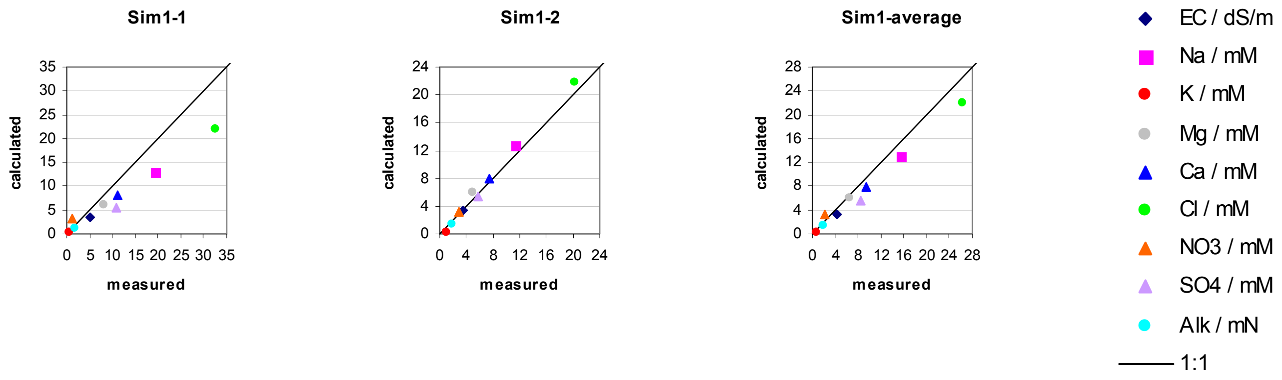

Figure 1. Scatter plots of predicted versus measured values in subplot 1

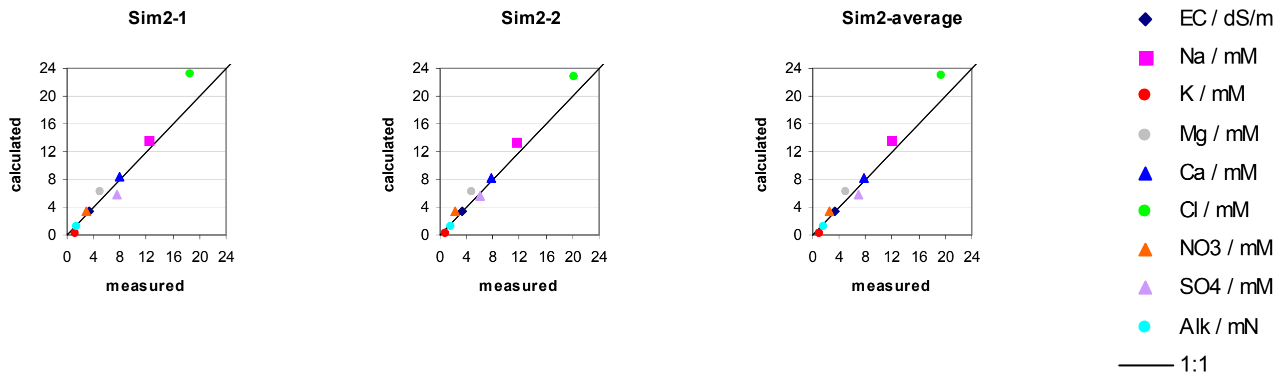

Figure 2. Scatter plots of predicted versus measured values in subplot 2

An alkalinity (Alk) of 1.30 meq/L was calculated in Sim1-1 and Sim1-2. This value is 26% lower than the alkalinity measured in point 1 (1.75 meq/L), and 31% lower than the measured alkalinity in point 2 (1.89 meq/L). The pH values calculated in the saturated pastes from both points were 7.84 and 7.85, thus very close to the measured values of 7.72 in both points.

Subplot 2 pepper

The soil composition saturation extract in points 1 and 2 calculated with SALTIRSOIL (Sim2-1 and Sim2-2 respectively) and comparison to the observed values are shown in Figure 2. The calculated values in Sim2-1 (3.48 dS/m) and Sim2-2 (3.43 dS/m) do not differ. For points 1 and 2, the measured EC_{se} are, respectively, 3.43 and 3.32 dS/m. Both EC_{se} points are located on the 1:1 lines, thus indicating that simulated and measured EC_{se} are very similar for both points. An alkalinity (Alk) of 1.29 meq/L was calculated in both points. This value is 14% lower than the alkalinity measured in point 1 (1.50 meq/L), and 22% lower than the measured alkalinity in point 2 (1.65 meq/L). The calculated pH values were 7.84 in both points, again very close to the observed values of 7.75 and 7.78 in points 1 and 2, respectively.

Discussion

Simulated and measured values for pH, EC, Alkalinity, and main inorganic ions in the saturation extracts are quite similar in subplot 2, but not in subplot 1. In general, surface irrigation systems lack of homogeneity in water application, and this heterogeneity increases with the size of the plot since amount and availability of water is lower as we get further from the inlet. On the other hand, Mediterranean soils are quite heterogeneous in nature and, particularly, those of alluvial origin under conventional horticultural practices that require removal of antecedent crop residues, ploughing etc. Then, irrigation plots are better characterized by spatial averages than by single point values. This statement particularly holds for the 1ha subplot 1. In fact, we observed differences in texture, drainage, actual amount of water available for crops and productivity depending on the relative position respect to the water inlet. Then, mean values in subplot 1 were calculated (Sim1-average). The mean measured electrical conductivity in subplot 1 is 4.34 dS/m and the mean calculated is 3.32 dS/m. In figure 1 (right scatter plot) we can observe that mean measured values are closer to those calculated than single values (centre and left scatter plots). Concerning to salt composition it is worthy to note that chloride seems to be over-predicted compared to other salts. A comparison of simulated and calculated values in more plots will be needed in order to ascertain whether this fact is due to a systematic error.

Acknowledgements

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Conclusion

SALTIRSOIL seems to predict accurately ion composition and electrical conductivity of saturation extracts in horticultural soils under surface irrigation systems. Nevertheless, in order to carry out a more complete validation, more irrigated plots and crops are necessary.

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Viability of lime and gypsum use in mitigating sodicity in an irrigated Vertosol

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Abstract
The use of gypsum, and to a lesser extent, lime to mitigate sodicity in dryland agriculture has been shown as viable. However, under an increased water application (i.e. irrigation) the dissolution of gypsum could be expected to be more rapid. Lime, due to a lower solubility, could provide a more constant source of calcium to the soil, especially when applied in combination with gypsum. This study investigates the effects of various rates of lime, gypsum and lime/gypsum combinations on an irrigated sodic Brown Vertosol in western NSW. The expected increase in soil EC due to gypsum was not evident after 6 months due to leaching. Additionally, only a high rate lime/gypsum combination was shown to have a positive effect on exchangeable calcium and sodium percentages, as well as aggregate stability. Short-term viability was not assessed efficacious after 6 months for any treatment. Potential for long-term viability was exhibited.

Introduction
Sodicity is inherent to many Australian soils and it is not a man-made problem, but a man-exacerbated one. Within New South Wales 47 % of soil is affected by sodicity (Northcote & Skene 1972) and the resultant clay dispersion. Subsequently, pore blockage, soil compaction and reduced hydraulic conductivity occur, resulting in an adverse soil environment. gypsum ($CaSO_4.2H_2O$) and, to a lesser extent, lime ($CaCO_3$) have been identified as ameliorants for sodicity that supply sufficient calcium to displace the excess sodium (Greene and Ford 1985; Shepherd 1925; So *et al.* 1978; Valzano *et al.* 2001). However, due to the solubility of gypsum (2410 mg/L), as compared to lime (15 mg/L), it is likely to dissolve and move further into the profile at a faster rate. Additionally, as Greene and Ford (1985) found that 120 to 130 mm of rainfall on a hard setting Red-Brown Earth (Red Sodosol) dissolved 1 t/ha of gypsum, it is fair to expect a more rapid movement of gypsum deeper into the profile of a Vertosol when subject to irrigation. Therefore, when considering chemical amelioration as a method to mitigate the effects of sodic topsoils there is a question of viability: should land-managers be trying to eradicate excess sodium, or should they accept the sodicity levels their topsoils contain and simply manage so as to not exacerbate these levels? This study examines the effects of common and exaggerated application rates of gypsum, lime and lime/gypsum combinations for their short-term stability effects on the topsoil, in order to assess the viability of such ameliorant application on an irrigated Vertosol.

Method
The experiment was conducted on an irrigated Brown Vertosol used primarily for cotton production, approximately 40 km north west of Hillston, in western NSW. Treatments ranged from a common application rate of 2.5 t/ha of either lime or gypsum to double rates (Table 3). Experimental full field 20 m wide strips (extending from head ditch to tail drain) were applied for each treatment and replicated twice. Sampling of the surface soil, 0 to 100 mm, was conducted in each treatment from the tail drain towards the head ditch after six months. During this six month period 10 ML/ha of water was used in 8 irrigation events for a cotton crop. Soil measurements included exchangeable cation analysis using Atomic Absorption Spectrometry consistent with Tucker (1985), Aggregate Stability in WATer (ASWAT; Field *et al*. 1997), pH and electrolyte concentration (EC). Further sampling will occur after 2.5 years, in December 2009, to a depth of 800 mm and will additionally incorporate full field hydraulic conductivity measurements using Irrimate™ (Purcell 2008), as well as satelite biomass imagery.

Results and discussion
Exchangeable sodium and calcium percentages
Within six months of treatment application, an expected trend was apparent for both the exchangeable calcium percentage (ECP) and exchangeable sodium percentage (ESP; Figure 5). In treatments where gypsum was applied, ECP generally increased and ESP generally decreased with increasing application rates. Conversely, ESP and ECP levels were maintained where lime was applied alone. In both cases the L5G5 and L2.5G5 treatments caused the greatest changes. However, for both ECP and ESP, only the L5G5 treatment

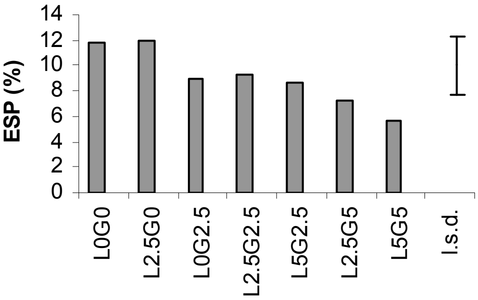
displayed a significant difference to the control. These results indicate that exchange of sodium with calcium has occurred within six months where gypsum is applied and that the effect is possibly greater when applied in combination with lime.

Table 3 Applied experimental treatments of lime, gypsum and lime/gypsum combinations with regard to calcium equivalent and cost.

Treatment	*Abbreviation*	*Lime (t/ha)*	*Gypsum (t/ha)*	*Calcium* Equivalent (t/ha)*	*Cost** (AUD$/ha)*
Control	L0G0	0	0	0	0
1	L2.5G0	2.5	0	1	275
2	L0G2.5	0	2.5	0.5	187.5
3	L2.5G2.5	2.5	2.5	1.5	462.5
4	L5G2.5	5	2.5	2.5	737.5
5	L2.5G5	2.5	5	2	650
6	L5G5	5	5	3	925

* Based on 200 kg/t of calcium in gypsum and 400 kg/t of calcium in lime (Abbott and McKenzie 1986).
** Based on actual expenditure including freight: lime AUD$110 per ton; and, gypsum AUD$75 per ton.

It is also recommended from this data that six months is not long enough to dissolve lime under irrigation at an initial pH of 8.2, irrespective of plant growth inputs. Furthermore, the rapid leaching of gypsum may not allow sufficient time for the calcium from gypsum to enhance lime dissolution through hydrogen displacement.



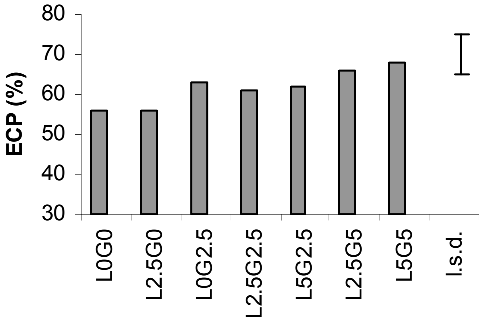


Figure 5. Exchangeable calcium percentage and exchangeable sodium percentage to 100 mm depth for the Mount View soil. Bars represent least significant differences (l.s.d.)

Electrical conductivity
From Error! Reference source not found. it can be seen that the soil EC was not significantly different between any of the treatments and the control, which is not consistent with findings of previous studies. Gypsum (Davidson and Quirk 1961; McKenzie *et al.* 1993) and lime (Naidu and Rengasamy 1993; Shainberg and Gal 1982) have both been shown to cause an initial increase in electrical conductivity (EC).Valzano *et al.* (2001) observed significant differences in EC due to gypsum application after one year in a dryland system. Subsequently, the observed soil EC effect declined after three years; the decline attributed to leaching via rainfall. For the irrigated Mount View soil, the total water applied, including rainfall, was 1209 mm/ha for the six month period. Considering the solubility rates for gypsum, 120-130 mm/ha dissolving 1 t/ha, observed by Greene *et al.* (1985), it is suggested that most of the gypsum has dissolved and been leached from the 0 to 100 mm layer. It is not suggested that an initial raise in EC has not occurred, rather that the magnitude of wetting has caused it to have occurred and subsided within six months. Depending on the magnitude of the period in which this EC flux has occurred, important implications for mitigating dispersive properties for seedling emergence are apparent.

Aggregate stability
Aggregates from all treatments and the control were potentially dispersive according to ASWAT, which is supported by the soil chemical data. However, the proportion of aggregates to undergo spontaneous dispersion in the L5G5 treatment differed significantly to the control, and the L5G5 treatment was observed to have a significantly lower dispersion index than the control soil. However, the majority of aggregates in

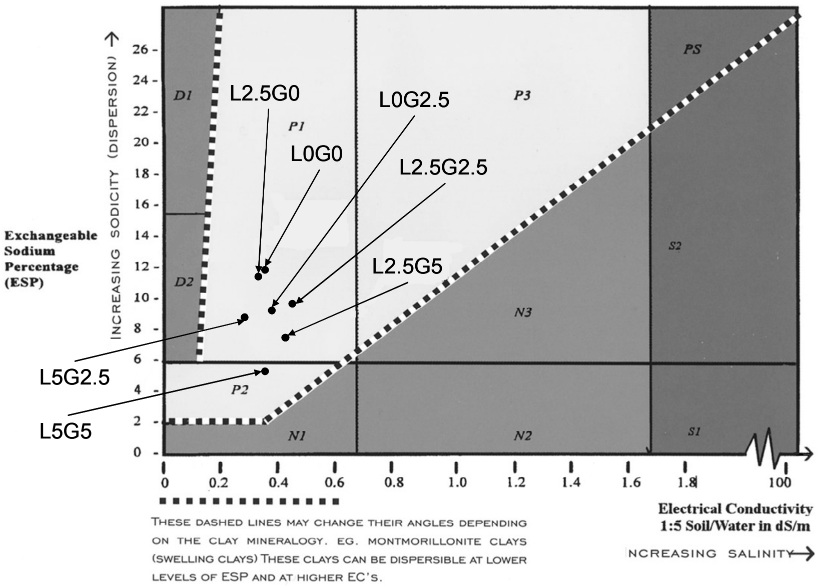
the L5G5 treatment did disperse to some degree after reworking, which could be expected given the ESP is proximal to the sodicity defining threshold of 6 % (Sumner 1993). These results suggest that irrespective of lime and gypsum application, the soil under all treatments remain potentially dispersive to some degree.

Table 4. Mount View 0 – 100 mm soil chemical attributes after 6 months from ameliorant application (Cations are exchangeable; α = 0.05)

Treatment	*Ca*	*Mg*	*K*	*Na*	*CEC*	*EC*	*pH*
			cmol(+)/kg			*dS/m*	
L0G0	3.50	2.02	0.03	0.73	6.29	0.35	8.2
L2.5G0	3.59	2.02	0.02	0.76	6.39	0.37	8.7
L0G2.5	4.45	1.99	0.02	0.63	7.09	0.39	8.4
L2.5G2.5	4.15	2.02	0.03	0.63	6.83	0.43	8.5
L5G2.5	4.37	2.05	0.20	0.59	7.04	0.32	8.7
L2.5G5	4.90	1.95	0.01	0.54	7.40	0.40	8.5
L5G5	4.99	1.89	0.02	0.41*	7.32	0.38	8.5
p value	0.06	0.10	0.51	0.01	0.17	0.62	0.4

** treatments with significant difference to L0G0 at respective p-value*

The ESP/EC matrix (Figure 6) shows the dispersive potential of the Brown Vertosol decreasing with application of gypsum, which may suggest that lime has had no influence on cation exchange. However, a meaningful difference is observed between the L5G5 and L2.5G5 treatments where only the former has fallen in the P2 zone. The importance of this result is that if EC declines at this same ESP then the L5G5 treated soil will not revert to be spontaneously dispersive, which all other treatments have the potential to do. Furthermore, both the L2.5G5 and L5G5 treatments have received 5 t/ha of gypsum. However, only the L5G5 treatment falls in the P3 zone as well as showing significant difference in ESP, which suggests the difference may be due to a possible synergistic effect of gypsum and lime at high rates.



Zone	*Sodicity*	*Salinity*
D1 & D2	Severe dispersion	No limitations
P1, P2, & P3	Potential dispersion	No limitations (P3 slight to moderate)
N1, N2 & N3	Nil dispersion (N1 low dispersion)	Slight to moderate limitation (N1 none)
S1 & S2	Nil dispersion	Severe limitations
PS	Dispersion with working	Severe limitations

Figure 6. Mount View ESP/EC matrix for depth 0 to 100 mm (after McKenzie and Murphy 2005)

Extension

Gypsum has previously been shown to provide a heightened EC in the short term, leading to many landholders using lower applications of gypsum to flocculate the soil in the germination and establishment phase of their crops and pastures. However, this study suggests that irrigation speeds up the EC flux.

Depending on this, the use of such a management strategy may not be efficacious. Therefore, an in depth investigation into the longevity of the EC effect under irrigated soils in the first six months would be of benefit.

Conclusions

The initial rise in soil EC had subsided within 6 months due to leaching, where in dryland agriculture the same EC raise has been recorded as lasting upwards of one year. This may hold important ramifications for seedling emergence and establishment.

Rapid gypsum dissolution was caused by the increased magnitude of water passing into the soil from irrigation and rainfall. However, under the same circumstances, lime applied alone did not display any increase in dissolution. Therefore, it was concluded that six months is too short a time period for lime dissolution to have a significant ameliorative effect on an alkaline, irrigated sodic soil. However, when applied as 5 t/ha in conjunction with gypsum at 5 t/ha there is evidence of a greater effect than when the same amount of gypsum is applied with 2.5 t/ha of lime. This suggests there is potential for a synergistic effect in the long-term. This is an important result as this synergy caused by the combination of lime and gypsum could provide a more constant source of calcium to the topsoil.

Furthermore, the use of the common application rate of 2.5 t/ha for these ameliorants was shown to cause little improvement in soil surface sodicity on the irrigated Vertosol. This leads to the preliminary conclusion that the use of lime or gypsum alone at the conventional rate is not a viable means of mitigating sodicity in the short-term. Conversely, even though the high rate application of lime and gypsum in combination showed significant improvement in soil structure it is not possible to draw the conclusion that such a treatment is viable. The cost of lime and gypsum in combination at the highest rate is substantial and outweighs the improvement in structure in the short-term. Hence, the longevity of this effect needs to be assessed over time to determine the overall viability of treatments, although the high rate treatments do show potential.

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Yield and salinity relationships in a country-scale soil and yield field-crop database

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Abstract

Soil and yield field-crop databases are much sought for understanding and predicting factors affecting crop yield. The optimal size of these databases is such that permits their general use but also secures good spatial representativity. In this paper the applicability of the Hungarian AIIR soil and yield field-crop database was tested for describing the effect of soil salinity on crop yields. The expected, already proven decreasing effect of soil salinity on yield was not substantiated by the database. In general the chemical soil properties showed the already proven relationships, but with very large scatter. By the example of a very small database it was shown that the inclusion of widely different soil types complicates the evaluation of the correlations very much. Increasing the number of data records with the inclusion of very different soil types can result in less useful global relationship between soil properties and yield.

Key words

Soil organic matter, chernozem, salt-affected soil, pH.

Introduction

Although there is plenty of knowledge available on the fundamental characteristics of soils, but the perfect knowledge of every soil aggregate is practically impossible. In spite of detailed physical, chemical and biological ground-truthing, the predictions carry statistical uncertainty due to the inherent variability of soil forming processes, management and the resulting soil properties. According to the scale of data collection the uncertainties of data and predicting capacity are expected to increase in the following order: physical and chemical equations < laboratory studies < pot studies < small plot experiments < controlled field experiments < uncontrolled field databases. But since in this order the areas and variation of occurring combinations of soil forming factors is increasing, the overall usefulness of the databases is generally increases. With the increase in uncertainty there can be a scale reached at which there are hardly any relationships that can be used for practical predictions due to the following reasons: inhomogeneity of analytical, data collection, datasourcing techniques, etc (Tóth *et al*. 2007). Therefore every use of databases must be preceded by the process of validation whether the database is suitable for the intended use or not. In this paper the results of the checking of a national soil and yield field-crop database are presented for its usefulness in the prediction of soil and yield relationships, preceded by an internal check of consistencies.

Materials and Methods

For this work the Hungarian "AIIR" soil and yield field-crop database ("Big database") (Tóth *et al*. 2005) was used. Data were collected in the years between 1985 and 1989 from the agronomic field records kept at the farms. These plowlayer data were collected from 60 000 fields covering yearly 4 000 000 ha. From the database the following data were utilized: applied fertilizer level, yield, soil analytical data (pH, Saturation Percent according to Arany method [SP_Arany], Soil Organic Matter content [SOM], soil salinity-Total Dissolved Solutes [TDS]). For ANOVA three fertilizer levels were selected, and named by the applied N level (90, 150 and 210 kg/ha). Average applied K and P were 87, 94, 110 and 65, 67, 68 kg/ha respectively in the mentioned levels).

Data from Ristolainen *et al.* 2009 were also used ("Small database"). The 70 m long transect was crossing non saline Chernozem tall grassland and extremely saline-sodic-alkaline calcareous shortgrassland patches. Samples (0-20 cm) were taken from every fifth meter. Soil clay content, pH, organic matter content (SOM) and electrical conductivity (EC of 1:2.5 soil:water suspensions) were determined according to Buzás 1988.

Results

The first question was whether the database shows the obviously expected decrease of crop yield with increasing salinity or not? Two soil main types, the most productive "Chernozems" (Mollisols) and "Salt-affected soils" and two major crops, the relatively salt tolerant winter wheat and the less salt tolerant

sunflower were selected. As shown below only in the case of Salt-affected soils we found the expected trend, and only in the case of sunflower it was statistically significant.
Correlation coefficients between soil salinity (%) and yield with number of observations in brackets based on the Big database

Soil/Crop	Winter wheat	Sunflower
Chernozems	0.04 (17269)	0.056** (4088)
Salt-affected soils	-.021 (1687)	-41.705

Since fertilizer level can affect the yield (Petróczi 2009) we have checked its effect on crop yield in the Big database as shown below with the number of cases in brackets. Means followed by the same letter are not statistically significant.

	Chernozems			Salt-affected soils		
Crop/Nitrogen Category (kg/ha)	**90**	**150**	**210**	**90**	**150**	**210**
Winter wheat (t/ha)	5.15a(2534)	5.24a(4182)	5.38b(2158)	4.02a(101)	4.12a(405)	4.39a(115)
Sunflower (t/ha)	2.16a(1491)	2.16a(196)	2.26a(50)	2.12a(115)	2.50a(10)	2.9a(1)

Although the tendency of the yields was increasing with increasing N level, there were no statistically significant differences in general between the nitrogen fertilizer categories. Generally sunflower is not considered to be very sensitive for larger fertilizer doses (Petróczi 2009), but this feature was not substantiated by the database. Moreover the salt-affected soils showed somewhat higher sunflower yields than the Chernozems, which is not very likely. Based on these observations the yield data are not considered to be suitable for the analysis of the relationship between soil salinity and crop yield.
Subsequently the second question was whether the proven relationships between soil properties can be detected or not? Table 1 compares the total and salt-affected data sets. A striking feature of the database is that it is not the group of Salt-affected soils which has the largest pH and salinity values.

Table 1. The descriptive statistics of the samples of the Big database for chemical properties

	TOTAL	SOIL	DATABASE	SALT	AFFECTED	SOIL TYPES
	N	Minimum	Maximum	N	Minimum	Maximum
pH (KCl)	286136	3.11	9.33	3627	3.22	8.00
SP_Arany	286136	24	81	3627	24	76
$CaCO_3$ (%)	286136	.00	33.00	3627	.00	33.00
SOM (%)	286136	.00	5.50	3627	.61	5.50
TDS (%)	168218	.01	2.20	3516	.01	2.20

Table 2. shows that there is a contradiction between the correlation coefficients between SOM and pH calculated for the total Big database and those calculated for the subset of salt-affected soils. Due to its acid character the soil organic matter is expected to show negative correlation with pH as it is shown by the salt-affected soils. For the total database the explanation is that the acidic soils typically have smaller SOM than the slightly alkaline Chernozems which are dominating the soil cover and the database.
For understanding the mentioned contradiction the Small database was evaluated, because it contained these variables and was collected in a rather well investigated area. In Table 4 there is no contradictory signs of correlation coefficient between the two halves. The reason is that the composition of the sample was balanced: 7 non salt-affected vs 8 salt-affected samples. Due to the wider range of values (Table 3) of salt-affected soils, there are rather contrasting "hidden" tendencies inside the joined database (Figure 1), but the salt-affected soils will determine the sign of overall correlation. As it is conceivable in this area salinity correlates with alkalinity and sodicity due to the presence of sodium carbonate. In Figure 1.A and B. there is opposite sign of correlation for the separate soil groups, but the sign of global correlation coefficient is determined by the extreme salt-affected soils. In Figure 1.A. the decreasing pH of non saline soils (red) is the consequence of the presence of SOM. The greater the SOM content the less $CaCO_3$ is remaining and therefore the pH decreases in the non saline soils. Since SOM contributes to electrical conductivity EC is increasing. On the other hand increasing salinity caused by alkali (green) will result in extreme high pH values. In Figure 1.B increasing amounts of SOM contribute to the increased measured value of electrical

conductivity (red) and therefore there is positive relationship for non salt-affected soils. But increasing salinity limits biological activity and there is negative relationship for salt-affected soils (green).

Table 2. The upper right part (in red) indicates the correlation matrix for chemical soil properties in the total Big database and the lower left part (in green) indicates the subset of salt-affected soil types according to Table 1. (** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).). Correlation coefficients with opposite signs are shown with the same coloured box pairwise.

	pH (KCl)	SP_Ar	$CaCO_3$	SOM	TDS
pH (KCl)	1	-.042**	.564**	.214**	.032**
SP_Arany	-.049**	1	-.009**	.680**	.245**
$CaCO_3$ content	.467**	-.194**	1	.167	-.006*
Soil Organic Matter	-.111**	.341**	-.012	1	.153**
Total Dissolved Solutes	.146**	.493**	-.043*	.111**	1

Table 3. The descriptive statistics of the samples of the Small database

	TOTAL	SOIL	DATABASE	SALT	AFFECTED	SOIL TYPES
	N	Minimum	Maximum	N	Minimum	Maximum
pH_2.5 (H_2Ol)	15	7.95	10.5	8	9.75	10.5
Clay content (%)	15	20	38	8	20	38
SOM (%)	15	.24	2.65	8	.24	.68
EC_2.5 (dS/m)	15	.17	4.05	8	.86	4.05

There is no contradiction in Figure 1.C, but rather the two tendencies support each other. The reason is the acidifying effect of organic matter. In Figure 1.D increasing clayiness goes together with increasing SOM as is usual for non saline soils (red), but for salt-affected soils increasing clayiness means increasing adsorbed sodium and salinity (green), which would limit biological activity and consequently SOM.
Table 4. The upper right part (in red) indicates the correlation matrix of the total Small database of Transect 2. and the lower left part (in green) indicates the subset of salt-affected soil types according to Table 3. (** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).)

	pH_2.5 (H_2O)	Clay	SOM	EC_2.5
pH_2.5 (H_2O)	1	.695**	-.982**	.823**
Clay content	.245	1	-.641*	.729**
SOM	-.849**	-.293	1	-.771**
EC_2.5	.721*	.467	-.684	1

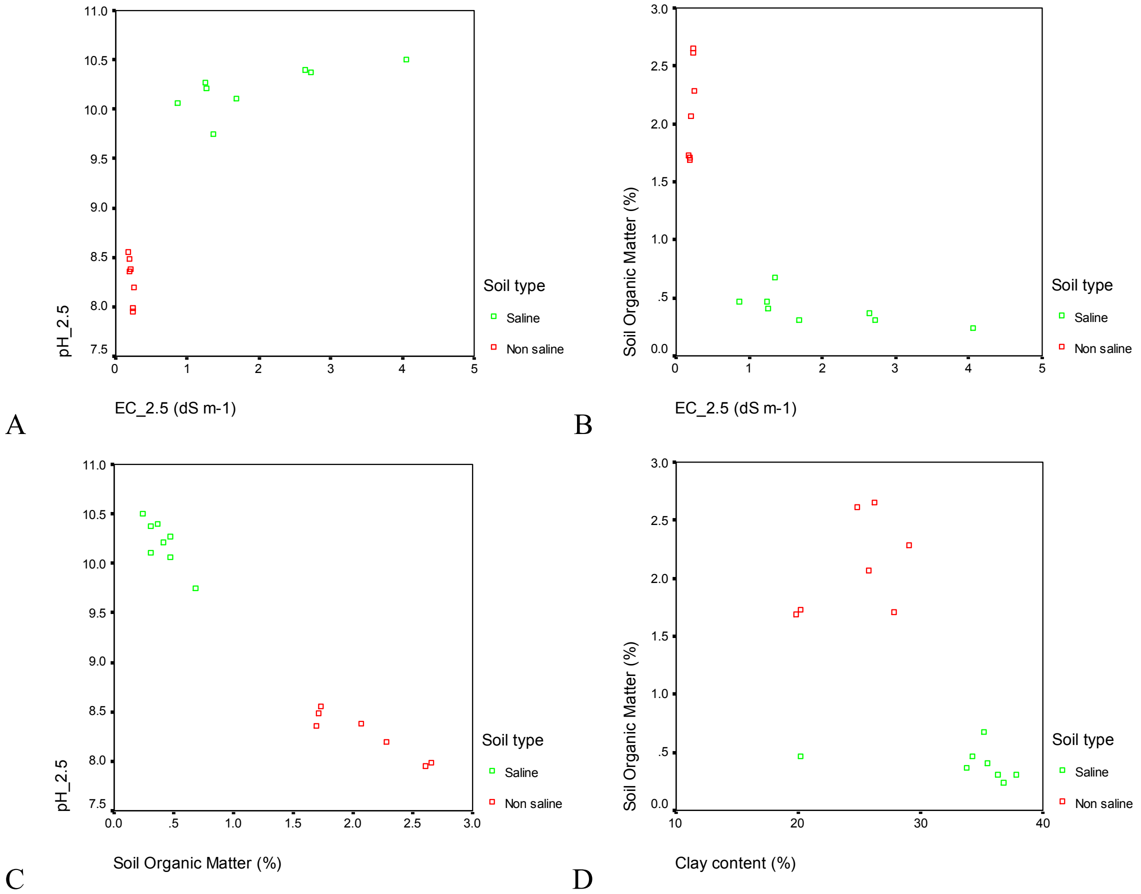

Figure 1. Scatterplots of soil chemical variables. A. soil salinity versus pH., B. soil salinity versus soil organic matter, C. soil organic matter versus pH, D. soil clay content versus soil organic matter. "Saline" indicates salt-affected soils, "Non saline" indicates supposedly Chernozems.

Conclusions

In small databases the contradictory tendencies of soil properties can be explained. But in large mixed soil and yield field-crop databases originating from varied landscapes and widely different soils, it is not easy to understand the relationship between soil properties and the yield.

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Acacia nilotica: A tree species for amelioration of sodic soils in Central dry zone of Karnataka, India

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Abstract
Acacia nilotica is a leguminous tree species commonly found in interior Karnataka on sodic soils was evaluated for its potentiality to reclaim the sodic soil in Hosadurga taluk of Chitradurga district, Central dry zone of Karnataka,. The results indicated that *Acacia nilotica* plantation over a period of ten years had achieved a marked reduction in saturated extract pH throughout the soil profile and ECe to a depth of 30 cm. A good improvement in saturated extract Ca, Mg and K was noticed throughout the profile depth. However, sodium and anions were drastically reduced in the surface but accumulation of Na and carbonates were noticed at lower depth. Due to reduction in Na^+ and increase of Ca^{2+} and Mg^{2+}, the exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) were also declined in the soil profile. An appreciable improvement in organic carbon, CEC and available major nutrients status of sodic soil was noticed due to tree stand over a period of ten years. Root length and canopy width which are the most important traits for bio-reclamation of sodic soils showed significant and negative association with pHs and ESP while association with CEC was found significant and positive in a desirable direction.

Key words
Salt-affected soils, Bio-rejuvenation, Physico-chemical properties, Saturated extract properties, Growth parameters, Correlation

Introduction
India has a very low per capita land availability of about 0.3 ha and vast areas have lost their productivity due to soil salinity and alkalinity (Shukla and Misra 1993). Reclamation of salt-affected soils and other wastelands will reduce the pressure on the productive lands to fulfill the mouth of the growing population of our country. Therefore, it has become imperative to develop the marginal and sodic wastelands under productive land use system. Planting site-matched tree species in these areas exerts bio-ameliorative effects for their reclamation, in addition to providing forest cover, fuel wood, fodder, timber and preventing water loss through run-off and soil erosion besides improving the micro-climate of that area. Tree roots can act as potential tillage tools to improve soil permeability and release appreciable amount of CO_2 (Robbins, 1986a). This CO_2 solubilizes the soil lime resulting in the release of a reasonable quantity of soluble Ca^{2+} for replacing excess Na^+ present on the exchange complex (Robbins 1986b). The replaced Na^+ is removed either below the root zone or out of the soil profile due to leaching of salts. *Acacia nilotica* is a thorny leguminous tree grown in interior Karnataka, which grows well in water logged, saline, sodic and marginal lands. In this context, an attempt has been made to assess the potentiality of *Acacia nilotica* to reclaim sodic soils.

Methods
Experimental Site
The study area is located in the Hosadurga taluk of Chitradurga district, a part of Central dry zone of Karnataka, India. The soils of the study site are representative of large areas of sodic soils and have been classified as Chromic Halpustalf (Soil Survey Staff 1994). Karnataka State Forest Department, Hosadurga, established the *Acacia nilotica* plantation on sodic wasteland ten years back. The topography is undulating plateau with an average elevation of 800 - 900 m above sea level. The mean maximum monthly temperature ranges between 25.4^{0}C in January to a maximum of 36.4^{0}C in April. The mean monthly minimum temperature varies between 13.3 to 19.8^{0}C during the month of December with a relative humidity of 48.13 to 70.50 per cent. Mean annual rainfall of the area is 567.6 mm. Most of the rainfall occurs in the months of September and October.

Collection and Analysis of Soil Samples
A site supporting 10-year-old plantation of *Acacia nilotica* was selected, and four spots each of 10 m^2 in four

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opposite directions were marked. In each spot, one soil profile was excavated at a distance of one meter away from the stem and one profile from nearby barren land was also excavated for the purpose of evaluating the changes undergone by soil due to *Acacia nilotica* plantation. Soil samples were collected from fixed depths of 0-15, 15-30, 30-60 and 60-90 cm from each profile. The soil samples, thus collected, were processed and analysed for their chemical composition like pH_s, EC_e, organic carbon, CEC, available nitrogen, phosphorus and potassium, saturated extract cations *viz.*, Ca^{2+}, Mg^{2+}, Na^+ and K^+ and anions *viz.*, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-} using standard procedures. The exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) were calculated using the methods given by Richards (1954).

Growth Parameters and Statistical Analysis
Stem diameter at stump height (DSH), stem diameter at breast height (DBH), number of branches per tree, canopy width, tree height, root length and roots weight were measured in all the selected sites using the procedures described by Misra (1968). In order to evaluate the bio-ameliorative effect of *Acacia nilotica* tree species on sodic soils, various tree growth parameters recorded were correlated with soil chemical parameters by simple correlation matrix for their significance both at 5 and 1 per cent levels by adopting the procedures outlined by Sundararaj *et al*. (1972).

Results

Effect on Soil Reaction (pHs) and Electrical Conductivity (ECe)
Active desodification was observed under *Acacia nilotica* plantation (Table 1). A remarkable reduction in pHs and ECe of saturated soil paste extract was observed after ten years of tree growth. Although pHs decreased more in the surface layer than at lower depths of soil profile under tree cover in comparison with barren site. However, it was declined at lower depth of study. Soil reaction (pHs) reduced from 9.2 (control) to 7.9 in the surface soil (0 - 15 cm) of *Acacia nilotica* plantation. The study showed that pHs < 8.5 was found throughout the profile depth studied under tree cover. This value is considered to be a threshold that separates the sodic soils from nonsodic soils (Soil Science Society of America, 1997). The greater decrease in pHs of the upper soil layer compared to lower layers in comparison with the barren site may be due to the replacement of Na^+ during Na^+-Ca^{2+} exchange and subsequent leaching (Qadir *et al*. 1996). Likewise, soil electrical conductivity (ECe) declined to an extent of 45 per cent in the surface soil (2.05 dS m^{-1}) from its initial barren soil value of 3.73 dS m^{-1}. This study also showed that the soluble salts leached down below 30 cm of soil profile. This was due to root penetration of tree plantation in the soil that provided channels for the percolating water.

Effect on Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR)
A remarkable decrease in ESP and SAR values at 0 - 15 cm soil depth after ten years of reclamation from their initial values of 50 to 27 and 32 to 11, respectively was recorded and the decrease was remarkable throughout the profile depth studied with respect to ESP whereas decrease of SAR values was upto a depth of 60 cm. This might be due to the production of CO_2 from decaying roots of tree plantation (Robbins 1986a) which solubilizes $CaCO_3$ present in the soil and releases soluble Ca^{2+} for the exchange reaction with Na^+ on clay complex (Robbins 1986b) and subsequent leaching due to root penetration of tree plantation in the soil that provided channels for the percolating water or Na^+ uptake by the plant roots (Qadir *et al*. 1997). After ten years of reclamation, SAR of the surface soil was <15%. This value separates sodic soil from nonsodic soils.

Effect on Saturated Extract Cations and Anions
The impact of *Acacia nilotica* plantation over ten years on the saturated soil paste extract of Ca^{2+}, Mg^{2+} and K^+ increased throughout the profile depth as compared to barren site and their concentrations were more in the surface soil and decreased with increase in depth of soil profile, whereas a reverse trend was observed with respect to Na^+ concentration in the soil profile. It was interesting to note that the Na^+ concentration decreased in the upper layers and increased in the lower layer probably due to leaching of soluble salts that became possible as a result of improvement in internal drainage consequent upon tree growth (Mishra *et al*. 2002) and accumulated at lower depth.

Carbonates, bicarbonates, chlorides and sulphates were drastically reduced to an extent of 40, 100, 64 and 47%, respectively in the surface soil as compared to nearby barren site. However, at lower depths, the accumulation of CO_3^{2-} was noticed due to *Acacia nilotica* plantation. The decreased anions level under tree cover over ten years was due to increased litter fall, organic carbon content of soil and tree roots activities

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which upon decomposition produce organic acids which favoured dissolution and translocation of HCO_3^- in soils. These results are in confirmation with the findings of Nadagouda (1996).

Effect on Organic Carbon status and Cation Exchange Capacity (CEC) of soil
The organic carbon content of soil was increased throughout the profile depth. However, the increase was more pronounced in the surface layer of soil profile. Nearly four-fold increase in organic carbon content of soil was observed in *Acacia nilotica* plantation after ten years of tree growth and it was increased from initial value of 0.60 to 2.29 per cent in the surface soil. The CEC of soil that was low in surface layer of barren site [43 cmol(p^+) kg^{-1}] increased to 55 cmol(p^+) kg^{-1} under tree cover over ten years of growth and it had a more impact on CEC of soil to a depth of 90 cm from the surface. The increased CEC due to *Acacia nilotica* plantation may be attributed to accumulation of organic matter and humus in the planted site over ten years of tree growth and this humus as organic colloid, play a major role in enhancing the CEC of the soil (Mishra 2002).

Effect on Available Major Nutrients
The available nitrogen, phosphorus and potassium content of soil were increased throughout the profile depth due to tree growth over ten years as compared to barren site. Available nitrogen content of soil was increased to an extent of 60 per cent from initial value of 280 to 447 kg ha^{-1} in the surface layer. This might be due to increased organic matter content of soil as a result of large quantities of leaf litter fall under tree cover (Yadav and Singh 1970). The available phosphorus and potassium content of soil were also increased from 4.3 to 17.0 kg P_2O_5 $ha^{-1}$and 228 to 273 kg K_2O ha^{-1}, respectively in the surface layer of the soil profile. The per cent increase in available phosphorus content of soil did not differ much with increasing depth of soil profile whereas the per cent increase in available potassium content of soil was more pronounced at lower depths of soil profile as a result of *Acacia nilotica* tree growth over a period of ten years.

Table 1. Impact of *Acacia nilotica* plantation on chemical properties of sodic soils (Mean of four profiles)

Depth (cm)	pHs	ECe (dS m^{-1})	OC (%)	Available major nutrients (kg ha^{-1}) N	P_2O_5	K_2O	CEC [cmol(p^+)k g^{-1}]	ESP
0-15	7.9 (9.2)	2.05 (3.73)	2.29 (0.60)	447 (280)	17.0 (4.3)	273 (228)	55 (43)	27 (50)
15-30	8.0 (8.9)	3.08 (4.16)	1.05 (0.53)	318 (145)	11.6 (3.2)	237 (141)	52 (40)	33 (51)
30-60	8.4 (9.2)	5.20 (5.07)	0.93 (0.40)	260 (123)	12.1 (3.2)	208 (129)	47 (37)	39 (55)
60-90	8.4 (8.8)	5.55 (3.55)	0.41 (0.29)	147 (85)	10.8 (3.2)	156 (66)	45 (33)	40 (60)

Table 1 Contd...

Saturated extract cations and anions (me L^{-1}) Ca^{2+}	Mg^{2+}	K^+	Na^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	SAR
2.6 (1.9)	2.0 (1.3)	3.4 (3.0)	17.0 (40.8)	5.1 (8.4)	0.0 (5.0)	15.5 (43.0)	4.3 (8.1)	11 (32)
1.9 (1.6)	1.5 (1.1)	2.8 (2.3)	21.1 (33.3)	6.1 (6.7)	0.0 (5.8)	23.8 (37.5)	5.8 (9.0)	17 (29)
1.3 (0.9)	1.1 (0.6)	2.1 (1.9)	25.5 (26.1)	7.5 (6.0)	1.0 (3.5)	27.3 (30.1)	5.1 (6.7)	25 (30)
0.9 (0.5)	0.5 (0.2)	1.6 (1.1)	28.5 (20.8)	8.2 (7.5)	0.0 (2.8)	28.9 (30.0)	5.2 (5.7)	36 (35)

*Figures in parenthesis indicate the nearby barren land profile value

Correlation of Soil Characters with Growth Parameters of Acacia nilotica
All the growth parameters except root weight exhibited significant and negative correlation with pHs and ESP while correlation with CEC was found significant and positive in a desirable direction (Table 2). The two important traits *viz.*, root length and canopy width depicted significant and negative association with pHs (-0.7498 and -0.7291, respectively) and ESP (-0.8328 and -0.8163, respectively) while association with CEC was found significant and positive (0.7855 and 0.6808, respectively). However, root length further depicted significant and negative association with SAR (-0.6764) and Na (-0.5593) and root weight with ECe (-0.7313).

Table 2. Relationship between *Acacia nilotica* growth parameters and properties of sodic soil

Soil properties / Growth parameters	pHs	ECe	Na	CEC	SAR	ESP
DSH	- 0.7432**	- 0.0313	- 0.4761*	0.7093**	- 0.3656	- 0.8182**
DBH	- 0.7364**	- 0.0804	- 0.4818*	0.7159**	- 0.3780	- 0.8029**
No. of branches	- 0.7104**	- 0.1479	- 0.3937	0.6057**	- 0.2649	- 0.7946**
Canopy width	- 0.7291**	- 0.0112	- 0.4569*	0.6808**	- 0.3257	- 0.8163**

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Tree height	- 0.7095**	- 0.0918	- 0.4924*	0.7171**	- 0.3833	- 0.7927**
Root length	- 0.7498**	- 0.2200	- 0.5593*	0.7855**	- 0.6764**	- 0.8328**
Root weight	- 0.1609	- 0.7313**	- 0.1099	0.0118	- 0.1626	- 0.1835

*Significant at P = 0.05 **Significant at P = 0.01

Conclusion

This can be concluded that *Acacia nilotica* tree species is able to rehabilitate the sodic soil and this tree species not only grows well in harsh sodic conditions but also can ameliorate the saturation extract properties. The pHs, ECe, ESP and SAR decreased whereas, the concentration of Ca^{2+} and Mg^{2+}, organic carbon content, CEC and available major nutrients status of soil increased in the soil profile, which clearly indicated its effectiveness in reclamation of sodic soils. The anions concentration decreased in the saturation extract of soil profile, which reveals favourable changes in the ionic composition of soil solution. Although *Acacia nilotica* reclaim the sodic soils effectively, yet a few more years are required for this tree species to bring the soil to normal level with respect to pHs, ECe, ESP and SAR. The overall growth of *Acacia nilotica* was hindered by soil pHs and ESP and improved by CEC of the soil.

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Global Warming induced Sea Level Rise on Soil, Land and Crop Production Loss in Bangladesh

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Abstract
Available data have been analyzed to assess impacts of global warming induced sea level rise on loss of soil and land resources and their implications on food security of Bangladesh. Scientists believe that because of sea level rise coastal zone of Bangladesh has already experienced noticeable impacts especially in terms of area of inundation and erosion, saline intrusion, loss of soil and land, loss of crop production in addition to migration of people from vulnerable areas. The loss of land mass and degradation of soil and land resources will adversely affect national food production and thereby food security. Sea level rise impacts are really high for Bangladesh, though the country plays insignificant role in green house gas emission. Development and implementation of adaptation policies and taking initiatives to realize those policies are the right ways to respond to sea level rise impacts in Bangladesh.

Key words
Climate change, sea level rise, soil and land resources, adaptation policies

Introduction
Rising sea level inundates low lying lands, erodes shorelines, exacerbates flooding, and increases the salinity of estuaries and aquifers. Some developing countries are especially exposed to sea level rise due to their low lying nature and limited financial resources to respond. Among the most vulnerable are countries with large populations in deltaic coastal regions such as Bangladesh, Vietnam, China and Egypt. The present paper analyzes the sea level rise impacts on soil and water salinity, agriculture and possible policy interventions in coastal areas of Bangladesh.

Geographical Location and vulnerability of Bangladesh
Bangladesh is situated at the north eastern region of South Asia and is bounded by India to the west, north and north-east and by Myanmar to the south east and the Bay of Bengal to the south. It has an area of 147,570 km^2 and a population of about 129.6 million, giving a population density of 874 per km^2. The country generally enjoys a sub-tropical monsoon climate. The country has a very flat and low topography except in the northeast and southeast regions. About 10% of Bangladesh is hardly 1m above the mean sea level and one-third is under tidal excursions. Huq *et al*. (1995) estimated that 11% of the country's population lives in the area threatened by a 1 m sea level rise.
The country has two contrasting environments to the north and the south. It has the Himalayas and the Khasia-Jaintia hills to the north and the Bay of Bengal and the northern Indian Ocean to the south. Both of these settings control, modify and regulate the weather and climate of the country and the region. The geographical location and geo-morphological conditions of Bangladesh have made the country one of the most vulnerable ones to disasters in the world.

SLR impacts
According to Nicholls and Leatherman (1995), a 1m sea-level rise would affect 6 million people in Egypt, with 12% to 15% of agricultural land lost, 13 million in Bangladesh, with 16% of national rice production lost, and 72 million in China and "tens of thousands" of hectares of agricultural land.
More than direct land loss due to seas rising, indirect factors are generally listed as the main difficulties associated with sea-level rise. These include erosion patterns and damage to coastal infrastructure, salinization of wells, sub-optimal functioning of the sewerage systems of coastal cities with resulting health impacts (WHO 1996, chapter 7), loss of littoral ecosystems and loss of biotic resources.
The SLR will inflict its impacts on Bangladesh in the coastal area and through the coastal area, on the whole of Bangladesh. About 2,500, 8,000 and 14,000 km^2 of land (with a corresponding percentage of 2%, 5% and 10% with respect to the total land area of the country) will be lost due to SLR of 0.1m, 0.3m and 1.0m respectively.

About one-fourth of the population lives in the coastal area. The rest depend in some way or other, on the activities in the coastal area. There will be likely migration of people from the coastal area further inland, thus putting pressure on non-coastal area as well. Thus SLR is going to affect the whole country.
Increase in SLR may cause migration of a lot of people inland, thus raising the population density there and causing socio-economic problems. Because of scarcity of land and high population density, northward migration may be limited, thus exposing these people to more hazardous condition**.**

Salinity intrusion
Sea level rise will bring more coastal area under inundation. This coupled with reduced flows from upland during winters will accelerate the saline water intrusion inland. Coastal waters will become more saline and soil salinity will increase. Not only that, even the ground water aquifers will bear the brunt of salinity intrusion. Winter crops in the coastal area which depend on ground water for irrigation will suffer a lot. Agriculture, forestry and fisheries sectors will be severely affected by increased water and soil salinity.

Extent of soil salinity in 1973 and 2000
Fresh river water withdrawal from upstream, irregular rainfall, introduction of brackish water shrimp

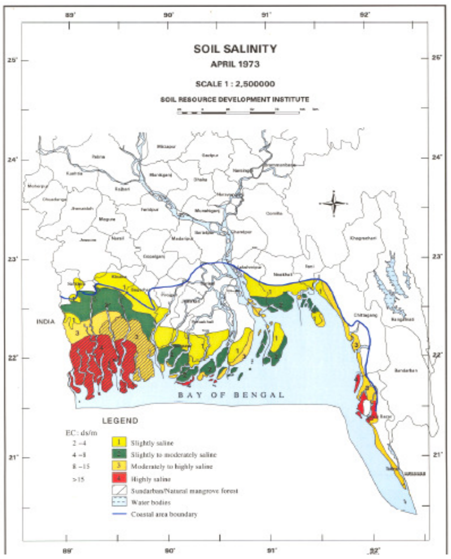

Figure 1. Soil salinity map of Bangladesh 1973. (Source: SRDI 1998)

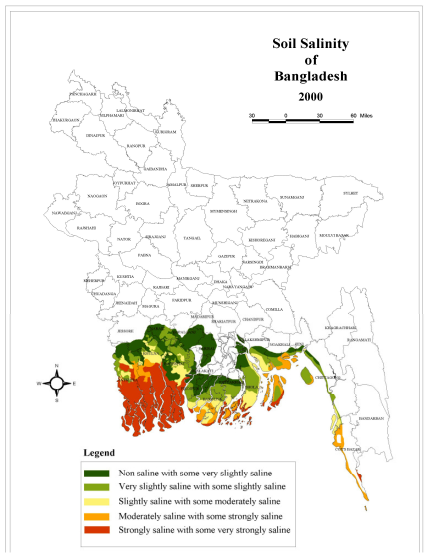

Figure 2. Soil salinity map of Bangladesh 2000 (Source: SRDI 2000)

cultivation, faulty management of the sluice gates and polders, regular saline tidal water flooding in unpoldered area, capillary rise of soluble salts etc. are the main causes of increased salinity affected area in this region. A comparative study between Soil Salinity map of the period of 1973 and 2000 shows intrusion of soil salinity in the coastal region (Figure 1 and 2). The map shows that soils of Jessore, Magura, Narail, Faridpur, Gopalgonj and Jhalakati were newly salinized in 37 years of time expansion. A comparative study between salinity survey in 1973 and 2000 showed that about 0.170 million ha (20.4%) new land is effected by different degree of salinity during last three decades (Table 1).

SLR and Agriculture

Solar radiation, temperature, and precipitation are the main drivers of crop growth; therefore agriculture has always been highly dependent on climate patterns and variations. Since the industrial revolution, humans have been changing the global climate by emitting high amounts of greenhouse gases into the atmosphere, resulting in higher global temperatures, affecting hydrological regimes and increasing climatic variability. Global warming is projected to have significant impacts on conditions food supply (how much food is produced) and food security.
More than 30% of the cultivable land in Bangladesh is in the coastal area. Out of 2.86 million hectares of coastal and offshore lands about 1.0 million ha (SRDI 2000) of arable lands are affected by varying degrees of salinity. Farmers mostly cultivate low yielding, traditional rice varieties during monsoon

Table1. Extent of soil salinity during last three decades (1973-2000) in coastal areas

District	Salt affected area (000'ha)		Salinity class								Salinity increase over 3 decades	
			S1 2.0-4.0 dS/m		S2 4.1-8.0 dS/m		S3 8.1-16.0 dS/m		S4 >16.0 dS/m		Area (000'ha)	Per-cent
	1973	2000	1973	2000	1973	2000	1973		1973	2000		
Khulna	375.04	402.69	48.79	88.97	255.68	118.25	49.84	157.94	20.73	47.53	27.65	7.37
Jessore	0	26.12	0	17.35	0	7.15	0	1.62	0	0	26.12	100.0
Jhalakati	0	3.41	0	2.28	0	1.13	0	0	0	0	3.41	100.0
Barisal	60.74	132.65	27.97	55.12	32.77	42.81	0	29.55	0	5.17	71.91	118.39
Patuakhali	219.05	234.00	165.16	71.16	53.89	71.33	0	78.41	0	13.10	14.95	6.82
Gopalganj	0	10.51	0	5.93	0	3.22	0	1.36	0	0	10.51	100.0
Madaripur	0	1.19	0	0.79	0	0.40	0	0	0	0	1.19	100.0
Faridpur	0	10.06	0	5.78	0	3.12	0	1.16	0	0	10.06	100.0
Noakhali	78.04	78.43	18.84	24.20	53.49	27.32	5.71	19.16	0	7.75	0.39	0.70
Chittagong	100.58	104.90	25.64	15.27	31.36	33.29	24.34	45.80	19.24	10.54	4.32	6.03
Total	833.45	1003.96	286.40	286.85	427.19	298.02	79.89	335.00	39.97	84.09	170.51	20.4

Source: SRDI 2001.

season. Most of the lands remain fallow in the dry season (January- May) because of soil salinity, lack of good quality irrigation water and late draining condition (Karim *et al*. 1990; Mondal 1997 and SRDI 2001). Crop production of the salt affected areas in the coastal regions differs considerably from non saline areas. Because of salinity special environmental and hydrological situation exists which restricts the normal crop production throughout the year. In the recent past, with the increase in degree of salinity in some areas due to saline water intrusion, normal crop production became very risky. Crop yields, cropping intensity, production levels and people's livelihood quality are much lower than other parts of the country, which have enjoyed the fruits of modern agriculture technologies based on high-yielding varieties, improved fertilizer and water management and improved pest and disease control measures (BBS 2001). At the same time food demand in the area is increasing with the steady increase in human population.

Scientists reported that salinity decreased the germination rate of some plants (Rashid *et al*. 2004; Ashraf *et al*. 2002). Ali (2005) investigated the loss of rice production in a village of Satkhira district and found that rice production in 2003 was 1,151 metric tons less than the year 1985 corresponding to a loss of 69 per cent. Out of the total decreased production, 77 per cent was due to conversion of rice field into shrimp pond and 23 per cent was because of yield loss (Table 2).

Table 2. Declining rice production because of soil degradation

Crop (months covered)	**1985**	**1990**	**1995**	**2003**
	Area under rice and shrimp farming (ha) (% of crop land)			
Aman (HYV); July – November	345.5 (100)	344.6 (100)	332.4 (97.0)	314 (91.9)
Boro (HYV); December - May	200.4 (58)	269.6 (78.2)	122.4 (32.8)	58.2 (17)
One shrimp cycle; December – January	36.5 (10.6)	75.0 (21.8)	210.0 (67.2)	255.8 (91.0)
Two shrimp cycle; December – November	0	0	20.6(3.0)	55.0 (8.0)
Expected total rice production	1373	1689	1679	1673
Observed total rice production	1265	1260	745	522
Decline in rice production due to loss of Area	108	221	670	890
Decline in rice production due to yield loss	-	208	264	261
Total loss of rice production	**108**	**429**	**934**	**1151**

(Adapted from Ali 2005)

A World Bank (2000) study suggests that increased salinity alone from a 0.3 meter sea level rise will cause a net reduction of 0.5 million metric tons of rice production.

Management approaches

To accommodate diverse land uses, changed patterns of land uses with land suitability, land zoning has been proposed as a management approach. Hossain and Lin (2002) suggested that, to reduce social conflict and promote effective and sustainable resource use land should be zoned on the basis of suitability- the most suitable zone, a moderate suitable zone and an unsuitable zone. The coastal zone policy states that ‘actions shall be initiated to develop land use planning as an instrument of control of unplanned and indiscriminate use of land resources’ and ‘zoning regulation would be formulated and enforced in due course’.

Conclusion

Bangladesh ranks low on just about all measures of economic development. This low level of development, combined with other factors such as its geography and climate, makes the country quite vulnerable to climate change. Higher population density increases vulnerability to climate change because more people are exposed to risk and opportunities for migration within a country are limited. With over 35% of Bangladeshis suffering from malnourishment (Lal *et al*. 2001), the threat of increased hunger from reduction in agricultural production would suggest the inclusion of agriculture as one of the major vulnerabilities facing the country. So, Bangladesh needs policy intervention to deal with climate change induced sea level rise impacts on natural resource management and food security.

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