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 $CaCO_3$) 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).

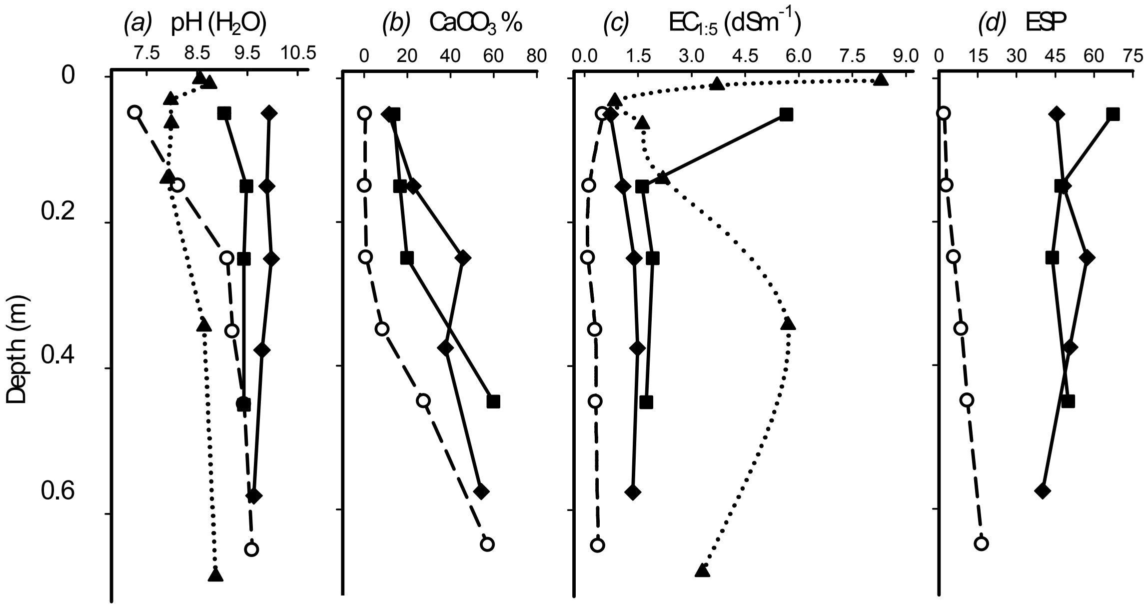

Fig. 1 Properties of smectite rich soils at the drained site, South 'poor' (○) and the undrained North 'good' (◆) and North 'poor' (■) sites, compared to the pH and EC measured for soil association J(▲) by Blackburn in 1950 prior to artificial drainage throughout this area. Open symbols are used here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

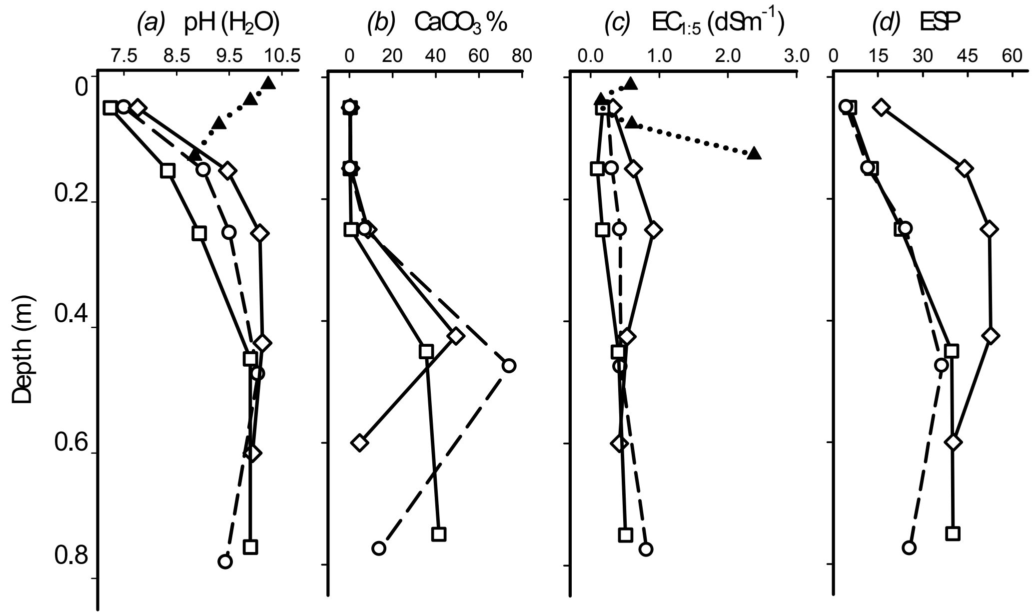

Fig. 2 Properties of illite/ kaolinite-rich soils at the drained sites of South 'good' (○), Central 'good' (◇) and Central 'poor' (□) sites, compared to the pH and EC measured of soil association R (▲) by Blackburn in 1950 prior to artificial drainage throughout this area.

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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