Alkaline sodic soils of the Yelarbon area, Australia

Andrew Biggs[A,B], Ben Harms[A] and Jim Payne[A]

[A] Department of Environment and Resource Management, QLD, Australia
[B] School of Land, Crop and Food Sciences, University of Queensland, St Lucia, QLD, Australia.

Abstract
Extremely alkaline and extremely sodic soils have been described in the area known as the Yelarbon 'desert', in southern inland Queensland, Australia. The soils are formed on current and relict alluvia at the junction of two rivers, on the eastern edge of the Great Artesian Basin, and have been strongly influenced by the upwelling of $NaHCO_3$ rich ground water. The land degradation observed in the Yelarbon area is in part related to the inherent suite of extreme soil properties, of which sodicity and alkalinity are key factors.

Key Words
Alkalinity, sodicity, salinity, groundwater, degradation, Yelarbon.

Introduction
Lying at the junction of Macintyre Brook and the Dumaresq River, just north of the Queensland-New South Wales border (Figures 1 and 2); the area around Yelarbon consists of landscapes unique in southern Queensland. Because of its barren appearance, the area is referred to as the Yelarbon 'desert'. The slightly to severely degraded landscapes have also been referred to as the Yelarbon 'salinity scald' (Knight *et al*. 1989). Until recently, detailed laboratory analysis existed for only one soil profile in the area of approximately 70 km^2. In the last few years, a number of shallow and deep soil profiles have been described and analysed, and mapping of the land units has been undertaken. The following provides a summary of the findings.

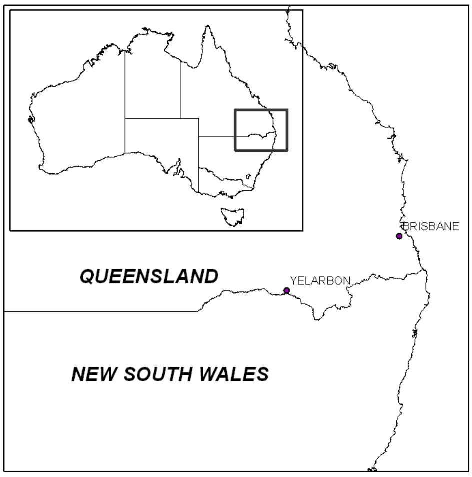

Figure 1. Locality of Yelarbon in Queensland, Australia.

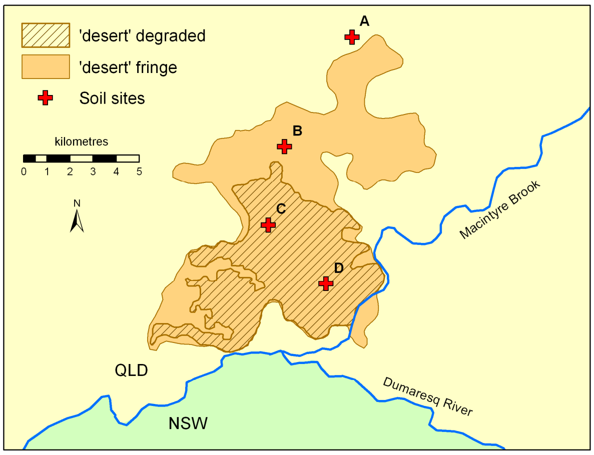

Figure 2. The Yelarbon study area. Results for Sites A, B & C are illustrated in Figures 3 & 5. Site D was described by Thwaites and Macnish (1991).

Soils and geomorphology
The first detailed soil descriptions for the 'desert' area around Yelarbon were provided by Isbell (1957). He drew attention to the very strong alkalinity of the soils and described them as 'solonetz' soils, referring to the presumed leaching of soluble salts through the profile. Thwaites and Macnish (1991) mapped a polygon called 'Desert' and provided analytical data for one soil profile. The profile they described was texture contrast in nature, with a thin silty loam surface over layers of clay. The whole profile was strongly alkaline, (subsoil pH 10-11), but only slightly to moderately saline (maximum EC = 0.81 dS/m at 0.9 m).

The 'desert' is comprised of slightly to severely degraded areas. The claypan-like appearance of much of the area is due to the removal of the surface soil horizons by sheet and wind erosion. In the severely degraded areas there is also rill and gully erosion with gullies reaching depths of up to 3 m. Vegetation is often completely absent in these areas.

Geology mapping (Mond *et al.* 1968) depicts the area as Quaternary cover (sand and soil), overlying Jurassic to Cretaceous sandstones (Kumbarilla Beds), with Quaternary alluvia along the rivers. To the east are outcrops of related sandstone; while to the west are extensive alluvial plains (both current and relict). At the regional scale, Yelarbon lies at the eastern edge of the Great Artesian Basin (GAB), where its sedimentary rocks lap onto metasediments (Texas Beds) of the New England Fold Belt. Various authors (Knight *et al*. 1989; Chen 2003; Biggs *et al*. 2005) have discussed the groundwater hydrology of the area. The general proposition is that over time there has been an upwelling of GAB waters due to a combination of geological faulting and hydraulic pressure. The GAB waters in this region are typically $NaHCO_3$ in nature, with high sodium adsorption ratios (SAR>50).

Vegetation

The Yelarbon 'desert' is mapped as spinifex grassland with scattered low trees and shrubs (DERM 2009), and is home to some locally unique species. It is the most easterly occurrence of the spinifex (*Triodia scariosa*) in southern Queensland, while the tea tree (*Melaleuca densispicata*) is limited to small isolated communities scattered across southern inland Queensland. Bull oak (*Allocasuarina luehmannii*) is also present in the scalded areas. The vegetation of the area is highly disturbed and degraded, with weeds such as mother of millions (*Bryophyllum* spp.) being common. Fensham *et al*. (2007) surveyed the vegetation of the scalded and non-scalded areas and refined the mapping of the 'desert' area (see Figure 2). They found that gradients in floristic patterns were primarily related to local drainage patterns and secondarily to soil pH.

Methods

Recent soil sampling in the area has been opportunistic in nature as part of other projects (e.g. Harms *et al*. 2008), and therefore site selection was not conducted in the manner normally used for a systematic soil survey in Queensland. Soil profiles were sampled with 50mm hydraulic driven soil cores (approx. 1.8 m length) or 43mm split tube percussion cores (Geoprobe) to maximum depths of 6 m. Profiles were described using methods outlined in McDonald *et al*. (1990), and samples (generally from 10 cm sections at 30 cm intervals) analysed at Department of Environment and Resource Management laboratories using standard methods outlined in Rayment and Higginson (1992). Soils were classified using the Australian Soil Classification of Isbell (1996). Mapping of land units has been undertaken using 1:40 000 aerial photographs and various types of satellite imagery (Landsat TM, SPOT).

Results

21 sites were described in the area, covering three main landscape types – degraded ('desert'), slightly degraded ('desert' fringe) and the sloping area outside the 'desert' in a transect running approximately north-south (see Figure 2). Selected soil properties for three sites (A, B and C) representing the three landscape types are illustrated in Figures 3 and 5. The soils outside the 'desert' (on the slope adjacent to the alluvial plain) are very different to the soils of the 'desert', but are typical of soil types in the surrounding area. They are pH inversion Vertosols, and have been included in this paper for the purposes of comparison. The following discussion relates to the 'desert' and 'desert' fringe soils of the alluvial plain.

Profile morphology and classification

Within the 'desert', soils are generally classified as Effervescent or Hypernatric Grey Sodosols. Stratified profiles (arising from alluvial deposition) are common. Silty to sandy textures are typical in the surface soil horizons, which are generally very thin and in many places have been removed completely. The subsoils are light to medium clay with a coarse prismatic to columnar structure. Textures may change to sandy loam in the deep subsoil or buried horizons. The soils of the 'desert' fringe are similar to the 'desert' soils, but are typically not as eroded and have higher clay content. Some are classified as Grey or Black Dermosols that are either Supercalcic or Hypercalcic. Fine-earth effervescence is common throughout the profiles, with the exception of A1 horizons (if they are present). Free carbonate (as soft and hard segregations) is generally prolific, and large patches (>10 cm) are often encountered.

Alkalinity

Soil profiles of the 'desert' are strongly to extremely alkaline throughout, with pH ranging from 9 to 9.5 at the surface to 10.5 or more at depths of more than about 20 cm. In the 'desert' fringe area, alkalinity reaches very high to extreme levels at approximately 80 cm; although the surface soil may be neutral or slightly acid (Figure 3a). The very high levels of alkalinity observed here are rare in Queensland and comparable to the most alkaline 'problem' soils reported for other parts of Australia (e.g. Adcock *et al*. 2007). Deeper sampling of the regolith material in the 'desert' fringe area showed that the very high pH levels continue to at least 6 m (see Figure 4).

Salinity
Salinity levels (as measured by electrical conductivity, EC) in the 'desert' and 'desert' fringe are variable but typically moderate, with maximum values generally attained in the upper B horizons (Figure 3b). In some soil profiles there is a strong correlation between EC and soil chloride (Cl) concentration indicating that the salinity is due largely to chloride salts. However, in other profiles (including those from the more degraded areas) chloride salts are a less significant contributor to conductivity, almost certainly indicating the presence of soluble carbonate salts. Sampling of the deeper regolith materials in the 'desert' fringe area showed no appreciable build up of salinity with depth.

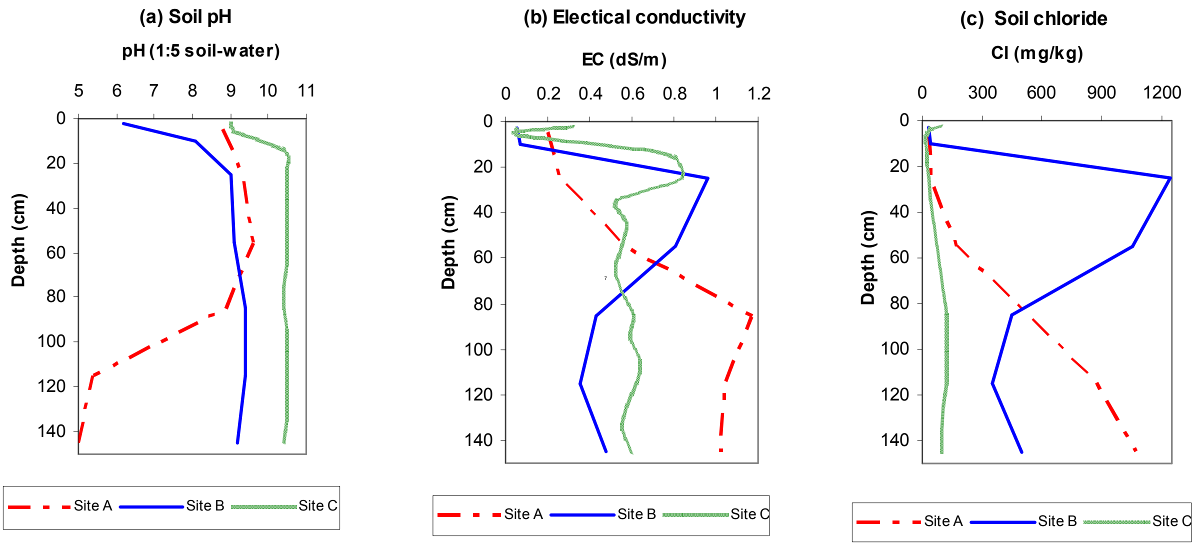

Figure 3. Soil profile properties (pH, EC and Cl) for three sites at Yelarbon. Site A is located outside the 'desert' area, Site B is in the 'desert' fringe, Site C is in the 'desert' degraded area; see Figure 2 for locations.

Cations and sodicity
The clay subsoils generally have a cation exchange capacity of between 20 and 30 meq/100g, and are almost fully base saturated. The exchange complex is dominated by sodium, with ESPs of >80, and in some cases almost 100% (Figure 5a). This obviously implies deficiencies of other cations, especially calcium (Ca) and magnesium (Mg), which are occasionally below detection limits. This is the case for both the 'desert' and 'desert' fringe soils, except that on the fringe, extreme ESPs are generally encountered slightly deeper, at about 50 cm (Figure 5a). Although these soils contain Ca^{2+} in the form of $CaCO_3$, the Ca remains 'unavailable' because at high pH, $CaCO_3$ is insoluble and tends to precipitate out of the soil.

Nutrient deficiencies and toxicities
Surface fertility is very low with deficiencies in all major nutrients. At high pH, deficiencies of phosphorus (P) are expected, as well as for the trace elements (Fe, Zn, Cu and Mn). On the other hand, boron (B) and molybdenum (Mo) are more soluble at high pH, and may be present in toxic amounts. In addition, if the pH is >10, sodium carbonate will almost certainly be present as a precipitate, and this is very toxic even at concentrations of 0.05-0.1% (Scholz and Moore 1998).

Soil physical properties
The clay content of the 'desert' and 'desert' fringe soils fluctuates with depth, which is a function of alluvial deposition. Despite field textures of medium clay being recorded, actual clay content is usually less than 30% (Figure 5b). Silt content is relatively high (>30%) in some profiles. Very high dispersion (R1) ratios (>0.96) were obtained for some soils. This is expected, given the extreme sodicity, and indicates that the clay minerals are almost completely dispersed. Bulk densities were measured for one soil profile on the 'desert' fringe and found to be approximately 1.6 g/cm^3 at 20 cm, increasing to >1.8 g/cm^3 below 1m soil depth. This indicates an excessively compact soil, with a restricted capacity for water movement, and hence root growth. Water infiltration also appears to be greatly restricted – as illustrated by the surface ponding that occurs even after light falls of rain. As a result, leaching fractions are likely to be low.

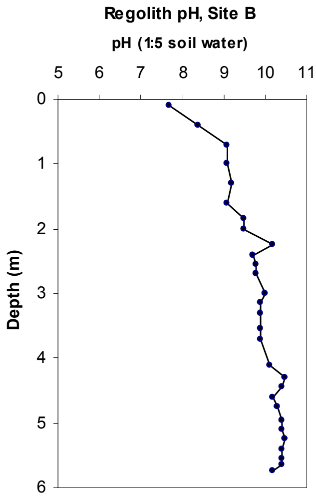

Figure 4. pH of the regolith profile to 6m depth at Site B ('desert' fringe).

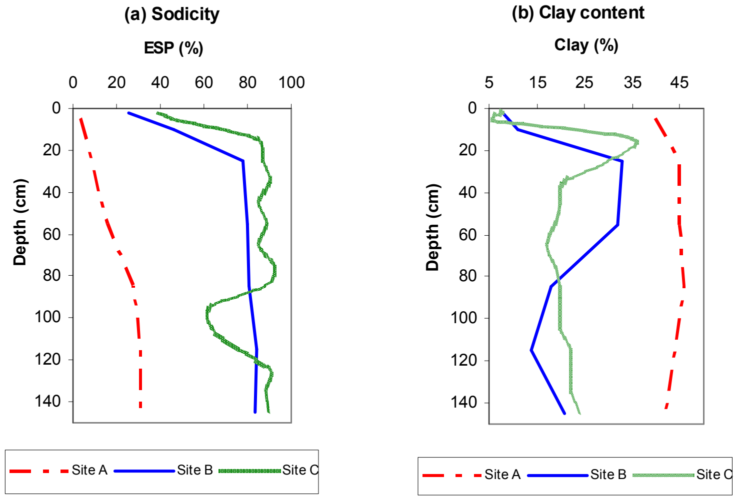

Figure 5. Soil profile properties (sodicity and clay content) for three sites at Yelarbon. Site A is located outside the 'desert' area, Site B is in the 'desert' fringe, Site C is in the 'desert' degraded area; refer to Figure 2.

Conclusion

The Yelarbon 'desert' is an area of extremely alkaline, extremely sodic soils whose nature has been strongly influenced by upwelling of GAB waters rich in $NaHCO_3$. While stratification exists in the current and relict alluvium of the Macintyre Brook and the Dumaresq River, alkalisation of soils is widespread within the degraded and fringing areas. The chemistry of these soils is unique in southern Queensland, and has been a key factor in the land degradation of the area.

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