Journal of Environmental Management xxx (2016) 1–8

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

# Managing land application of coal seam water: A field study of land amendment irrigation using saline-sodic and alkaline water on a Red Vertisol

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ARTICLE INFO

*Article history:*
Received 8 June 2016
Received in revised form
19 September 2016
Accepted 25 September 2016
Available online xxx

*Keywords:*
Coal seam gas
Coal bed methane
Gypsum
Threshold electrolyte concentration
Salinity
Sodicity

ABSTRACT

Coal seam (CS) gas operations coproduce water with gas from confined CS aquifers. This CS water represents a potential agricultural resource if the water is able to be chemically amended to comply with management guidelines. Stoichiometric quantities of sulphur and gypsum amendments can be used to neutralise the alkalinity and reduce the sodicity of CS water respectively. These amendments can either be mixed in-line at a water treatment plant or applied directly to land prior to the application of CS water (a practice termed land amendment irrigation - LAI). This study compared the efficacy of LAI with in-line chemical amendment of CS water and irrigation with non-saline, non-sodic and non-alkaline (good quality) water under field conditions in southern Queensland. Soil chemical properties, soluble Ca, Mg, K, Na, electrical conductivity (EC), pH, chloride and alkalinity, as well as saturated hydraulic conductivity were measured to determine the impact of the irrigation treatments on soil chemical and physical conditions. Irrigation of lucerne pasture using solid-set sprinklers applied a total of 6.7 ML/ha of each treatment irrigation water to the experimental plots over a 10-month period. Alkalinity was neutralised using LAI, with no increase in soil alkalinity observed. Soil sodicity did not exceed threshold electrolyte concentration values under either CS water irrigation treatment. Soil chemical and physical properties were comparable for both LAI and in-line chemical amendment of CS water. Soil saturated hydraulic conductivity was maintained under all irrigation treatments. Results showed that the constrained capacity of the irrigation system was unable to meet crop evapotranspiration demand. This resulted in accumulation of salt within the root-zone under the CS water treatments compared to the good quality water treatment. LAI successfully chemically amended Bowen Basin CS water facilitating its beneficial use for agricultural irrigation.



## 1. Introduction

Coal seam gas (CSG), synonymous with coal-bed methane and coal-bed natural gas, is an energy resource extracted through well heads from pressurised, confined coal seam aquifers. The Australian CSG industry contribution to real income is estimated to be ~AUD$231 billion throughout 2015 to 2035, in Queensland alone (Jakeman et al., 2012). Co-produced water from CSG wells is currently estimated to be 65 GL/annum (Office of Groundwater Impact Assessment, 2016). Whilst the industry provides revenue to governments, CSG extraction within Australia generally occurs on agricultural land resulting in the need for coexistence between gas production and agricultural industries. Coal seam (CS) water is considered a valuable resource for agriculture; particularly in subhumid regions where CSG is extracted. This has led to the Queensland State Government mandating that CS water be utilised under a beneficial use approval whereby irrigation is recognised as a beneficial use (Department of Environment and Heritage Protection, 2014). However, CS water within the Bowen and Surat Basins in Queensland is typically associated with geological formations that produce water containing Na–$HCO_3$–Cl dominated salts (Kinnon et al., 2010; Power et al., 2009; WorleyParsons, 2010). Coal seam water quality is variable with salinity measured as

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http://dx.doi.org/10.1016/j.jenvman.2016.09.078
0301-4797/

electrical conductivity (EC) ranging from 2.0 to 11.6 dS/m, sodium adsorption ratio (SAR) 56–124 and alkalinity 300–2860 mg/L $CaCO_3$ equivalent (Kinnon et al., 2010; WorleyParsons, 2010). The salinity, sodicity and alkalinity of CS water must therefore be amended prior to beneficial reuse in agricultural irrigation. (Raine and Ezlit, 2007).

While reverse osmosis is an effective method to remove sodium and bicarbonate from CS water, an alternative strategy is to chemically amend alkaline and sodic effects of the CS water using a source of acidity to neutralise its alkalinity and a soluble calcium source (e.g. gypsum) to ameliorate its sodicity (Ganjegunte et al., 2005). Commercial application of chemical amendments of CS water in-line at water treatment plants or at the soil surface have been effective in managing sustainable soil conditions within the Powder River Basin, Wyoming (Ganjegunte et al., 2008; Johnston et al., 2008, 2013; Vance et al., 2008).

The structural stability of soils under irrigation with different quality water (salinity and sodicity) is characterised by threshold electrolyte concentration (TEC) analyses. The TEC curve predicts the soil solution salinity (EC) required to maintain soil hydraulic conductivity (i.e. soil structural stability) at a specific soil solution SAR (Quirk and Schofield, 1955). TEC curves have been demonstrated as soil specific (Marchuk and Rengasamy, 2012; McNeal and Coleman, 1966; Menezes et al., 2014), even within the same soil orders (Bennett and Raine, 2012).

The objective of this study was to determine the efficacy of chemical amendment of CS water by LAI and in-line treatment under field conditions. Specifically the study sought to: (1) compare changes in key soil chemical properties under LAI, irrigation with in-line chemically amended CS water and irrigation with good quality water; and (2) evaluate if LAI maintained soil hydraulic conductivity as predicted by soil TEC analysis.

## 2. Methodology

### 2.1. Experimental site and design

The study was conducted northeast of Injune, Queensland, Australia (25°44′39.9″S 148°56′30.0″E). The soil type at the experimental site was a red Haplic Vertisol (IUSS Working Group WRB, 2014) overlying ferruginised sandstone and weathered mudstone. The depth to C horizon varied between 70 and 115 cm. The experimental site had a 1.0–2.0% slope from G3 towards E1, with a 1.0% slope from G3 to G1 and E3 to E1 (See Fig. 1). The soil had an A1 horizon (0–10 cm depth) of medium clay, B21 horizon (10–40 cm depth) of medium heavy clay and B22 horizon (from 40 cm depth) of medium heavy clay. The mineralogy for the soil was uniform with montmorillonite dominating (58%), associated with kaolinite (28%) and quartz (14%).

Treatments were arranged in a 4 × 4 Latin square design (van Es and van Es, 1993) where each plot consisted of an area 12 by 24 m (buffer of 36 m between plots) irrigated by six solid set sprinklers (Nelson Rotator: R33LP operating at between 30 and 35 PSI) with 12 m radial throw (Fig. 1). The site was proximal to a CS associated water amendment facility (AWAF) where CS water was treated in-line with sulphuric acid (~400 L/ML) and micronized gypsum (~400 kg/ML), to address solution alkalinity and sodium adsorption ratio (SAR), prior to being transferred to the field. Similarly, good quality irrigation water and untreated CS water were pumped to the experimental site. Accordingly, the treatments were: A) good quality water (GQW); B) untreated CS water with land applied gypsum and sulphur (LAI); and C) AWAF in-line treated CS water (ATN) (Fig. 1 and Table 1). Note an additional treatment (D), AWAF in-line treated CS water with land applied gypsum (ATG), was designed to manage the risk of soil structural

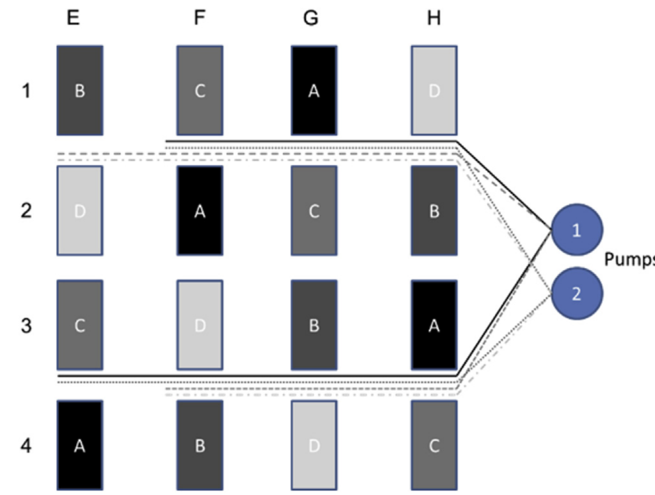


**Fig. 1.** Schematic diagram of the Latin square experimental site and irrigation layout both by treatment code A through D (Table 1) and by grid coding (Row x Column coordinates of E,F,G, or H x 1,2,3, or 4, respectively). Pump one irrigated good quality control water (A;—) and CS water (B;···), while pump two irrigated AWAF treated CS water to treatment C (—) and D (-··-), the removed ATG treatment.

degradation driven by rapid dilution of soil solution salinity during rainfall. However, very low rainfall was experienced during the experimental period which resulted in this treatment not being statistically different to the ATN treatment. Therefore, the ATG treatment has been precluded from further discussion. The precautionary dry season application of gypsum to offset rapid dilution of soil solution during heavy rainfall periods should be provided attention in further investigations.

Stoichiometric rates of sulphur and gypsum applied as treatments were determined to deliver an irrigation water (syn. with surface soil solution) SAR of 25 using the geochemical model PHREEQC Version 3 (Parkhurst and Appelo, 2013). Sulphur bentonite (90% elemental sulphur) and agricultural grade gypsum (75% pure) were used; gypsum was assumed to have 75% effective dissolution (Bennett, 2011). Amendment application rates are presented in Table 1. Initial application of amendment to address 2.25 Ml/ha irrigation occurred prior to irrigation commencing and was incorporated to 10 cm. Subsequent amendment was reapplied at the soil surface every 2.25 ML/ha of irrigation.

The irrigation system was designed to irrigate all plots within one day. Holding tanks for each water source limited the irrigation application rate to <20 mm per application. Irrigation events were manually operated at each pump and outflow data manually recorded using a flow meter pre-/post-irrigation, and the irrigation regime imposed is plotted in Fig. 2. Irrigation management was limited to daylight hours and when wind-speed was <9 km/h (Ruzicka, 1992). This resulted in an irrigation deficit of 1160 mm (11.6 ML/ha) over the experimental period compared to potential evapotranspiration demand (Fig. 2). Irrigation uniformity was assessed and the Christensen Uniformity coefficient was between 80 and 83% for wind-speed <1 km/h, which was considered adequate for experiment requirements (Kara et al., 2008).

The site has a subtropical climate with hot summers and cool winters. Rainfall concentrated in the summer months. Rainfall was measured using an *in-situ* calibrated weather station and five manual gauges distributed around the experimental site. The study site received 167 mm (1.67 ML/ha) of rainfall during the 10 months of the irrigation period (Fig. 2), which is well below the long-term regional average rainfall of 543 mm (5.43 ML/ha) over the same period (Bureau of Meteorology site 043015).