ECOLOGICAL ENGINEERING 33 (2008) 26–36

available at www.sciencedirect.com

ScienceDirect

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

Can crops be irrigated with sodium bicarbonate rich CBM deep aquifer water? Theoretical and field evaluation

Y.G. Beletse[a], J.G. Annandale[a,*], J.M. Steyn[a], I. Hall[b], M.E. Aken[c]

[a] Department of Plant Production and Soil Science, University of Pretoria, Pretoria 0001, South Africa

[b] Anglo Coal Project Services, Private Bag X9, Leraatsfontein 1038, South Africa

[c] Anglo Coal Environmental Services, Private Bag X9, Leraatsfontein 1038, South Africa

ARTICLE INFO

Article history:
Received 3 August 2007
Received in revised form
11 December 2007
Accepted 22 December 2007

Keywords:
Mine water
Modelling
Long term
Irrigation
Salt tolerance
$NaHCO_3$
SWB model

ABSTRACT

A simulation modelling exercise, followed by field trials was carried out to assess the suitability of sodium bicarbonate ($NaHCO_3$) rich water obtained from dewatering for extraction of methane gas from coal beds in the Limpopo Province, Republic of South Africa. This water has a very high EC of 750 mS m^{-1}, which according to FAO water quality guidelines would suit only salt tolerant crops. Modelled crop growth at a leaching fraction (LF) of 23% using the Soil Water Balance (SWB) model gave root zone salinity (EC_e) between 857 and 981 mS m^{-1}, and a 90% potential crop yield. In the field trials, barley, Italian ryegrass and Bermuda grass were successfully grown in a loamy sand soil without leaf burn and toxicity problems, but cotton foliage was scorched when sprinkler irrigated. Drip emitter discharge rate decreased from 3.99 ± 0.15 to 3.5 ± 0.19 l h^{-1}, suggesting that clogging will be problematic with micro irrigation. SWB gave a good estimation of the suitability of this $NaHCO_3$ rich water in the theoretical assessment, which was similar to the experimental findings. SWB, therefore, is a useful tool for assessing the suitability of $NaHCO_3$ deep aquifer water for irrigation of agricultural crops.

1. Introduction

Large coal reserves in the Waterberg district of the Limpopo Province of South Africa are being investigated for their possible exploitation as an energy source for the future. Where coal is too deep for open cast mining to be economical, the extraction of coal bed methane (CBM) is a possibility. In places, a 60 m thick coal seam is 250 m deep, and lies below the water table in a confined aquifer, the pressure of which retains methane in the coal. This work forms part of a broader feasibility study for methane extraction in the region and only a pilot plant is currently operational.

The extraction of CBM involves the reduction of pore pressure by withdrawal of groundwater from the deep confined aquifer, both above and within the coal seams by pumping water to the surface to allow the methane gas to be desorbed from the coal. Operators drill wells into the coal seams and enhance the release of methane by creating man made fractures in the coal bed that causes the methane to rise to the surface where it is currently flared, but in future could be piped to a compressor station for distribution.

During the dewatering phase of methane gas production, a large quantity of water is pumped to the surface, which because of its poor quality, needs to be managed carefully. The CBM water from the Waterberg is very saline–sodic, dominated by $NaHCO_3$, with a sodium adsorption ratio (SAR) of 85 (mmol l^{-1})$^{0.5}$, a total dissolved salt (TDS) concentration exceeding 5000 mg l^{-1}, and an electrical conductivity (EC) of around 750 mS m^{-1}.

* *Corresponding author*. Tel.: +27 12 420 3223; fax: +27 12 420 4120.
E-mail address: john.annandale@up.ac.za (J.G. Annandale).

0925-8574/$ – see front matter
doi:10.1016/j.ecoleng.2007.12.011

Discharging this water freely to streams or the shallow cleaner water aquifer will cause unacceptable pollution, and the South African National Water Act of 1998 places great emphasis on the protection of water resources for their sustainable utilization (Xu et al., 2002). Management options under consideration are to release the water into natural streambeds after treating it using reverse osmosis, re-injecting it back into the coal beds, precipitating salts in evaporation ponds or using the water for irrigation. Reverse osmosis is effective (Yuyao et al., 2000) but extremely costly, and may make the project economically unviable. Irrigation, if feasible, would clearly be a low cost beneficial use option to this water problem.

The use of saline and saline–sodic water for irrigation is receiving renewed attention with the increasing scarcity of freshwater resources in semi-arid regions (Alit et al., 2006; Hamdy and Ragab, 2006). Irrigated agriculture including that in South Africa, will in future be faced with the challenge of using such waters to provide food and fibre for the expanding population (Oster, 1994; Moolman et al., 1999).

In the last decade, mine wastewater has been used very successfully in South Africa for growing several crops, but it must be borne in mind that these waters were predominantly gypsiferous (Annandale et al., 2006). Planted pastures were also successfully irrigated in the short term with Na_2SO_4 rich mine effluent on a heavy clay soil (Beletse, 2004). Although these successes are encouraging, it must be taken into account that the CBM water is dominated by sodium bicarbonate ($NaHCO_3$) and is therefore quite different to the waters used in these examples. At present, the total volume of poor quality water that can be generated by the Waterberg CBM mine is estimated to be 2 million m^3 per year, and this will continue for about 30 years. However, at any one site, pumping and therefore potential irrigation, is likely to have a lifetime of only 15 years.

The elevated SAR and TDS levels of the Waterberg CBM deep aquifer bicarbonate rich water can potentially affect soil structure and plant growth negatively, even if managed carefully (Ayers and Westcot, 1985). HCO_3 can also affect plant growth through a decrease in the solubility of nutrients, which is caused by the increase of pH associated with increasing concentrations of carbonates (Tang and Robson, 1993). Two studies were carried out to assess the possibility of growing crops with this water. A theoretical assessment, which included a modelling study, to ascertain whether or not there is a reasonable chance of irrigating successfully with this water, before investing in field trials. The specific objectives were to identify the most suitable crops that could possibly be grown with such waters under the soil and climatic conditions of the area, and to identify suitable irrigation management options using the Soil Water Balance (SWB) model. In this initial step, the CBM water was assumed to have no impact on the soil physical properties as the model is unable to simulate changes in hydraulic properties. The second study was commissioned after the theoretical assessment, and involved experimental testing the feasibility of such irrigation in a field trial. The specific objectives were to investigate whether crops (namely, barley, ryegrass, cotton and Bermuda grass) irrigated with $NaHCO_3$ deep aquifer waters could survive and produce biomass; to observe whether foliage scorching under sprinkler irrigation is problematic; to observe if drip emitters clogged through salt precipitation; and to observe if soil physical problems would arise when irrigating with this sodium rich water.

2. Data

2.1. Climate

The study was carried out in the winter 2005 and summer 2005/2006 growing seasons in the Limpopo Province, Republic of South Africa. The average annual rainfall (November–April) of the area is about 411 mm (1982–2004). Average daily minimum temperatures range between −2 °C in winter (May–August) and 16 °C in summer (November–March), with maximum temperatures ranging from 24 °C in winter to 31 °C in summer. The area falls in the cotton–wheat agro-ecological zone of the province with wheat, cotton, barley, lucerne, maize and groundnuts being the major crops.

2.2. Soil

The soil at the trial site was a 1.4 m Hutton deep loamy sand (Soil Classification Working Group, 1991) with a clay content between 5 and 11%, and a water holding capacity of around 120 mm m^{-1}. Bulk density of the soil was 1.55 Mg m^{-3}. The soil was ploughed to 0.3 m depth and a rotavator was used to prepare a fine 0.2 m deep seedbed. As a result of the concern over potential infiltration problems, 1.2 t ha^{-1} gypsum ($CaSO_4{\cdot}2H_2O$) was applied in the winter irrigation trial. In the summer irrigation trial, however, 25 t ha^{-1} gypsum ($CaSO_4{\cdot}2H_2O$) and 40 t ha^{-1} sheep manure and crop residue mix were applied, as the gypsum applied in the winter irrigation trial was insufficient to counteract the infiltration problems that arose. Soil samples were taken after laying out the experiment (initial conditions) in July 2005, and again after harvest in October 2005 and June 2006. Sampling was done at 0.2 m intervals down to 1.4 m, and bulk density, pH, soil saturated electrical conductivity (EC_e), and ion concentrations (Ca^{2+}, Mg^{2+}, K^+, Na^+, $CO_3{}^{2-}$, $HCO_3{}^-$, Cl^- and $SO_4{}^{2-}$) were determined. Exchangeable sodium percentage (ESP) was calculated from Na concentrations and the CEC, both measured in units of $cmol_c\ kg^{-1}$.

2.3. Crop

Salt tolerant crops of barley (*Hordeum vulgare* cv. Puma), and a mixture of an Italian ryegrass (*Lolium multiforum* cv. Agriton (Diploid)) and stooling rye (*Secale cereale* cv. Echo) were planted in the 2005 winter season, whereas cotton (*Gossypium hirsutum* cv. Opal) and Bermuda grass (*Cynodon dactylon* cv. K11) were planted in the summer 2005/2006 season. A row spacing of 0.3 m and a seeding density of 120 kg ha^{-1} were used for barley, while the ryegrass–stooling mix was broadcast evenly at 60 kg ha^{-1}. Agriton prefers well-drained clay to loamy soils and a pH level below 5 for best results (Tainton, 2000). Echo is widely adapted to most soil conditions but does not perform particularly well on light, sandy soils (Tainton, 2000). The available soil may not, therefore, have been ideal for these fodder crops, but their tolerance to