

Impacts of winery wastewater irrigation on soil and groundwater at a winery land application site

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Abstract

This study examines the impact of winery wastewater irrigation on Red Calcarosols or Red Kandosols typically found in the Riverine Plain of South Eastern Australia. The winery water composition is variable but generally has high organic matter concentrations (>2000mg/L total organic carbon), high potassium and sodium salts (up to 1000mg/L) with associated sodium adsorption (SAR) and potassium adsorption (PAR) typically having values >7. Over the 2005-2008 period, surface soil sodium and magnesium tended to decrease in concentration, calcium remained relatively constant and potassium doubled. Total organic carbon (TOC) and pH remained relatively unchanged. Surface soil potassium concentrations increased due to the high concentrations of potassium in grape juice and the winery using potassium-based cleaning agents for winery tank sanitization. However, concentrations remained unchanged in sub-surface soils. Soil solution samples obtained from Full Stop Wetting Front Detectors™ (FSWFD) indicated that salinity concentrations at shallow depths (30cm) were controlled by irrigation water composition, while at deeper depths (60cm), high salinity groundwater (14dS/m) was the major influence. Off site impacts in terms of nutrient movement to groundwater were found to be of low risk in the heavy clay soils of this study.

Key Words

Effluent, carbon, nitrate, pollution, potassium, salinity

Introduction

The aim of this work was to assess the sustainability of a winery wastewater land-based disposal system by determining impacts on soil and groundwater. The dynamics of nutrients, salt, and total organic carbon (TOC) in soils, soil solution samples and ground waters were monitored over an irrigation season and integrated with subsidiary longer term data, collected over a 3 year period prior to and after wastewater irrigation.

Methods

Field Site Description

The study was carried out at a winery (~80,000 tonne crush) land based wastewater disposal site in the Murrumbidgee Irrigation Area (MIA) near Griffith, New South Wales, SE Australia. A 67 ha portion of land was divided into irrigation bays of ~3 ha each. Water (~3 ML/ha) was applied to the bays by a border-check irrigation system traditionally used on farms in the area. Introduction of wastewater to the field was *via* a pipeline from the winery into an open irrigation channel. Irrigation control structures ('stops'), at the head of each irrigation bay could be opened to allow each bay to be flood irrigated individually. River water, the usual irrigation water in the region, could also be supplied to the channel to dilute the wastewater as required. Further details of the site are described in an environmental assessment (De Bortoli Environmental Assessment Report, 2005). Over the period of our study (May 2006 – March, 2007), the land was cropped with winter barley in 2006 followed by a fescue crop in January 2007.

Field Trial Monitoring and Sampling

Monitoring equipment was installed in three irrigation bays. Each site consisted of an area of approximately 2m x 2m in which were installed the following equipment: an automatically logged test well and piezometer and two Full Stop Wetting Front Detectors™ (FSWFD - 30 cm and 60 cm depth). In one bay, EnviroSCAN® Soil Moisture Monitoring Equipment was an additional installation.

Table 1. Chemical characteristics of surface and sub-surface soils at the field trial site.

Soil Interval	0-10 cm	60-90 cm
pH	8.1	9.2
Clay content (%)	60	50
TOC (g kg ⁻¹)	0.5-1.6	
Salinity (dS m ⁻¹)	0.14	0.49
CEC (cmolc kg ⁻¹)	10	> 10
ESP (%)	3.1	12.8

Soil Sampling

Surface soil samples were collected by the winery in 2005, 2007 and 2008 and we conducted a sampling campaign during the 2006/07 irrigation season; soil cores were collected on 21/11/06 after harvest of a barley crop, on 11/1/07 immediately before the planting of a fescue crop and on 7/3/07 during the growth of the fescue crop. Soil cores were taken to 90 cm depth and divided into four depth intervals: 0-10cm, 10-30cm, 30-60cm, 60-90cm. Observations were also recorded at an adjacent site without wastewater irrigation.

Soil Description

Dominant soils were Red Calcarosols or Red Kandosols (Isbell 1997) which, respectively, are calcareous throughout the solum or have a weakly structured or massive, clayey, B horizon (De Bortoli Environmental Assessment 2005). The main properties of the soil are reported in Table 1.

Water quality

The mid-season soil sampling (11/1/07) occurred after an irrigation consisting of winery wastewater diluted with channel water and the end of season soil sampling (7/3/07) immediately followed an irrigation that consisted of undiluted wastewater (Table 2).

Table 2. Chemical characteristics of irrigation water consisting of winery wastewater shandied with regular irrigation water (sampled 18/12/06), undiluted wastewater (sampled 13/2/07) and groundwater (sampled 14/2/07)

Water Quality Parameter	Diluted Wastewater	Undiluted Wastewater	Groundwater
EC (dS/m)	2.2	4.7	14
pH	9.6	4.4	7.6
Calcium (mg/L)	9.7	399.9	222.0
Potassium (mg/L)	594.8	801	62.9
Magnesium (mg/L)	48.2	72.0	365.7
Sodium (mg/L)	95.9	97.7	2814.4
TOC (mg/L)	190.5	2148	221.3
SAR + PAR	13	7	27.7

Results

Soils

Surface soil samples collected by the winery between 2005-2008 revealed that soil sodium and magnesium approximately halved in concentration, calcium remained relatively constant and potassium doubled (Figure 1). However, the available data indicated that changes in pH and TOC were insignificant. By 2008, observation of the soil indicated a more friable, aggregated structure, a darker brown colour and a greater number of earthworms than observed in earlier years and in adjacent soils that had not undergone wastewater irrigation. Overall, in spite of increased levels of potassium, which potentially may affect soil structural stability (Arienzo *et al.* 2009), the soil structure and biological condition did not seem to be negatively impacted.

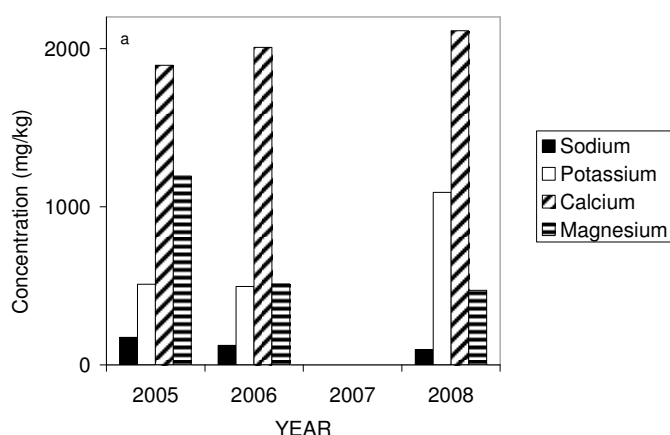


Figure 1. Changes in major cations prior to and proceeding three years of wastewater irrigation in surface soils at the land application site.

The soil samples we collected in 2006/07 indicate relatively low soil salinity in surface soils with large increases with depth (Figure 2).

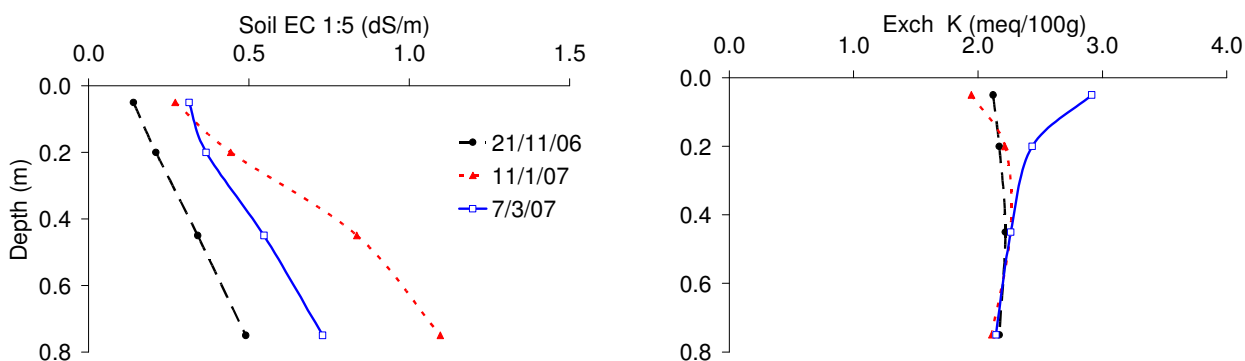


Figure 2. Soil EC_{1:5} and exchangeable potassium vs. depth at three different dates throughout one irrigation season.

After a crop of barley had been harvested, grown by irrigating with regular channel water showed that soil electrical conductivity (EC_{1:5}) increased from 0.14 dS/m at the surface to 0.4 dS/m at 60-90 cm. Over the period of the irrigation season, surface EC_{1:5} increased from 0.14 dS/m to 0.26 dS/m with large increases in sub-surface EC_{1:5} to > 1 dS/m. The latter can be accounted for by shallow groundwater tables rising to 0.3 m below the soil surface due to irrigation. Exchangeable sodium matched the EC_{1:5} trends. Surface levels of sodium increased marginally over the course of the irrigation period. Increases occurred from approximately 4 meq/100g to 10 meq/100g, mid season, then dropped back down to 6 meq/100g at the end of the season. Surface levels of potassium doubled over the course of the irrigation period from approximately 2 meq/100g - 4 meq/100g, with concentrations remaining unchanged below 20 cm (Figure 2).

Soil Solutions Salt

Salt concentrations in soil solutions obtained from the 30 cm FSWFD were higher overall than in corresponding irrigation water but showed the same temporal trends (Figure 3).

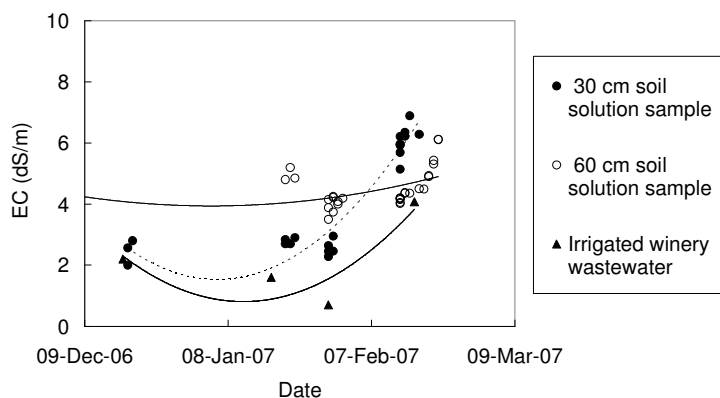


Figure 3. Trends in EC concentrations in soil solutions obtained from FSWFD at 30 cm and 60 cm depth over the 2006/07 irrigation season, compared with EC of corresponding irrigated wastewater

This indicated, at shallow depths, soil solutions were dominated by the irrigation water salts with some additional salt residues being picked up from the soil profile as the wetting front progressed. In contrast, soil solutions obtained from the deeper detector (60 cm) displayed salt concentrations that were fairly constant over time. The solutions obtained at 60 cm probably represent irrigation water mixed with high salinity groundwater (Table 2) which had risen due to the irrigation.

Total Organic Carbon (TOC)

The similarity in TOC of irrigation water and soil solutions at 30 cm indicates little attenuation in TOC occurs between the surface and the 30 cm detector (Figure 4). This seems unlikely in these heavy clay soils and suggests preferential flow is occurring between the surface and 30 cm depth.

By Days 5 and 6 after the start of irrigation TOC in the 30 cm samples had declined to approximately 40% of

its initial value (Day 0) probably through degradation. Similar concentrations to the 30 cm soil solutions are seen in the 60 cm solution samples suggesting, that by Day 5, breakthrough has occurred. By Day 7 the shallower parts of the profile are drying, allowing aerobic degradation and further TOC decline, while the deeper depths remain wetted, thus anaerobic and TOC concentrations remain elevated.

Nitrate and Ammonia

Soil solution samples from the 30 cm depth FSWFD representing irrigation water May-Dec, 2006 clearly reflected the application of urea that was used to establish the barley crop. Maximum concentrations of nitrate and ammonia were 21.1 mg/L and 1.1mg/L respectively recorded the day after urea application. For the subsequent crop of fescue, established in January 2007 and irrigated with diluted or raw winery wastewater, almost identical results from the 30 cm FSWFD soil solution samples were observed compared with those seen previously. This suggests that the impacts of crop fertilization on NO₃ in soil solution are much more significant than irrigating with winery wastewater in these soils. Relatively small peaks of nitrate (maximum 3.6 mg/L) were detected directly beneath the crop in shallow groundwaters around the time of winery wastewater irrigation.

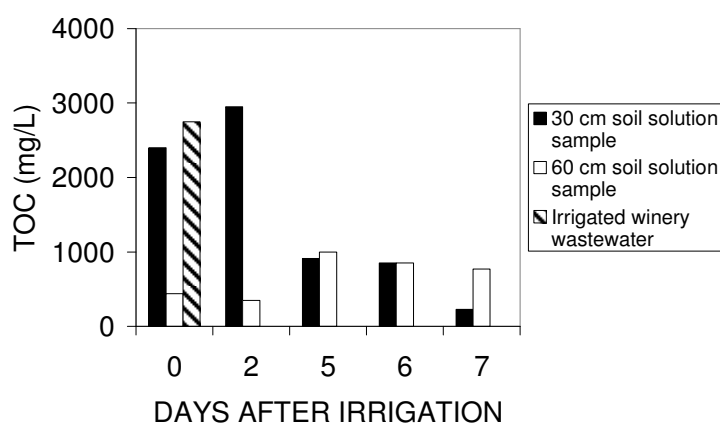


Figure 4. Distribution of TOC in soil solution samples collected from 30 cm and 60 cm FSWFD following irrigation, compared with TOC of irrigated wastewater

Conclusions

Salt and potassium accumulation occurred during winery wastewater irrigation, but in these clay rich soils mobility was low and the accumulation was restricted to surface soils. Cropping and soil management of the site needs to be managed appropriately to utilise and remove excessive potassium levels. (Arienzo *et al.* 2009 review how this can be achieved). However, highly saline groundwater (>10dS/m) which rises during irrigation maybe a more significant threat to soil sustainability than the quality of winery derived irrigation water.

TOC in soil solution samples indicated that there was attenuation of TOC between 30 and 60 cm depth at the start of the irrigation schedule but that breakthrough occurred at lower levels after 5- 6 days. Then, as the paddock dried, TOC tended to persist at higher levels deeper in the profile compared with at the surface. Relatively small peaks of nitrate were detected beneath the crop in shallow ground waters around the time of winery wastewater irrigation, below the 10 mg/L NO₃-N, that are considered acceptable for potable water use.

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