Changes in properties of vineyard Red Brown Earths under long-term drip irrigation, combined with varying water qualities and gypsum application rates

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by

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I dedicate this thesis to my grandmother (Nan)

Nora Theresa Clark

(13/4/1908-20/12/2000)

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Statement

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text.

I give consent to this copy of my thesis, when deposited in the University library, being available for loan and photocopying

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Louise Jayne Clark

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Summary

Irrigation water of poor quality can have deleterious effects on soils. However, the effect of drip irrigation on seasonal and long term (*e.g.* over 50 years) changes in soil chemical properties is poorly understood, complicated by the two-dimensional water flow patterns beneath drippers. Field and laboratory experiments were conducted, along with computer modelling, to evaluate morphological and physio-chemical changes in a typical Barossa Valley Red Brown Earth (Palexeralf, Chromosol or Lixisol) when drip irrigated under various changing management practices. This work focused on the following two management changes: (i) switching from long-term irrigation with a saline source to less saline water and (ii) gypsum ($CaSO_4$) application.

A literature review (**Chapter 1**) focuses on the distribution, features, properties and management of Red Brown Earths in the premium viticultural regions of the Barossa Valley and McLaren Vale, South Australia. The effects of irrigation method and water quality on the rate and extent of soil deterioration are emphasised. The review also discusses the irrigation of grapes (*Vitis vinifera*) and summarises previous research into the effect of sodicity and salinity on grape and wine characteristics. This chapter shows the importance of Red Brown Earths to Australian viticulture, but highlights their susceptibility to chemical and physical degradation. Degradation may be prevented or remediated by increasing organic matter levels, applying gypsum, modifying cropping and through tillage practices such as deep ripping.

Chapter 2 provides general information on the two study sites investigated, one in the Barossa Valley and the other at McLaren Vale. Local climate, geology, geomorphology and soils are described.

Chapter 3 details laboratory, field and sampling methods used to elucidate changes in soil chemical and physical properties following irrigation.

The genesis of the non-irrigated Red Brown Earth in the Barossa Valley is described in **Chapter 4**, and is inferred from geochemical, soil chemical, layer silicate and carbonate mineralogical data. Elemental gain and loss calculations showed 42 % of original parent material mass was lost during the formation of A and A2 horizons, while the Bt1 and Bt2 horizons gained 50 % of original parent material mass. This is consistent with substrate weathering and illuviation of clay from surface to lower horizons. The depth distributions of all major elements were similar; the A horizon contained lower amounts of major elements than the remainder of the profile, indicating this region was intensely weathered. This chapter also compares the non-irrigated site to the adjacent irrigated site (separated by 10 m) to determine if the sites are pedogenically identical and geochemical changes from irrigation. Many of the differences between the non-irrigated and irrigated sites appear to be correlated with variations in quartz, clay, Fe oxide and carbonate contents, with little geological variation between the sample sites.

In **Chapter 5** morphological, chemical and physical properties of a non-irrigated and irrigated Red Brown Earth in the Barossa Valley are compared. Alternating applications of saline irrigation water (in summer) and non-saline rain water (in winter) have caused an increase in electrical conductivity (EC_{se}), sodium adsorption ratio (SAR), bulk density (ρ_b) and pH. This has resulted in enhanced clay dispersion and migration. Impacts on SAR and ρ_b are more pronounced at points away from the dripper due to the presence of an argillic horizon, which has greatly influenced the variations in these soil properties with depth and distance from the dripper. Dispersion and migration of clay were promoted by alternating levels of EC, while SAR remained relatively constant, resulting in the formation of a less permeable layer in the Bt1 horizon. Clay dispersion (breakdown of micro-aggregate structure) was inferred from reduced numbers of pores and voids, alterations in colouring (an indication that iron has changed oxidation state) and increased bulk density (up to 30%). Eleven years of irrigation changed the soil from a Calcic Palexeralf (non-irrigated) to an Aquic Natrixeralf (irrigated) (Soil Survey Staff, 1999). These results, combined with data from Chapter 4, were used to develop a mechanistic model of soil changes with irrigation.

Chapters 6, 7 and 8 describe field experiments conducted in the Barossa Valley and McLaren Vale regions. This data shows seasonal and spatial variations in soil saturation extract properties (EC_{se}, SAR_{se}, Na_{se} and Ca_{se}). At the Barossa Valley site (**Chapter 6**) non-irrigated soils had low EC_{se}, SAR_{se}, Na_{se} and Ca_{se} values throughout the sampling period. The irrigated treatments included eleven years of drip irrigation with saline water (2.5 dS/m) and also gypsum application at 0, 4 or 8 tonnes/hectare in 2001 and 2002. Salts in the profile increased with gypsum application rate, with high levels occurring mid-winter 2002 prior to rainfall leaching salts. SAR has declined with gypsum application, particularly in the A horizon and at 100 cm from the dripper in the Bt1 horizon; this has the potential to reflocculate clay particles and improve soil hydraulic conductivity.

Chapter 7 presents further results from the Barossa Valley site, this treatment had been irrigated for 9 years with saline water (2.5 dS/m) prior to switching to a less saline water source (0.5 dS/m). The soil also received gypsum at 0, 4 or 8 tonnes/hectare in 2001 and 2002. It was found that the first few years are critical when switching to a less saline water source. EC declines rapidly, but SAR requires a number of years, depending on conditions, to decline, resulting in a period during which the Bt1 horizon may become dispersed. Gypsum application increased the EC_{se} but not to the EC_{se} levels of soil irrigated with saline water.

Chapter 8 examines soil chemical properties of a McLaren Vale vineyard, irrigated with moderately saline water (1.2 dS/m) since 1987 and treated with gypsum every second year since establishment. This practice prevented the SAR (<8) rising and a large zone of the soil profile (20 to 100 cm from dripper) has a high calcium level (>5 mmol/L). However, irrigation caused the leaching of calcium beneath the dripper in both the A and B horizons (0 to 20 cm from dripper) (< 4 mmol/L).

Chapters 9 and 10 interpret and discuss results from continuous monitoring of redox potential (Eh) and soil solution composition in the Barossa Valley vineyard, irrigated with saline or non-saline water, and gypsum-treated at 0 and 4 tonnes/hectare.

Soil pore water solution (**Chapter 9**) collected by suction cups is compared to results obtained in chapters 6 and 7. The soil has extended zones and times of high SAR and low EC. This was particularly evident in the upper B horizon, where the SAR of the soil remained stable throughout the year while the EC was more seasonally variable with EC declining during the winter months. The A horizon does not appear to be as susceptible to clay dispersion (compared to the B horizon) because during periods of low EC the SAR also declines, which may be due to the low CEC (low clay and organic matter content) of this horizon.

Chapter 10 presents redox potentials (Eh) measured using platinum redox electrodes installed in the A, A2 and Bt1 horizons to examine whether Eh of the profile varies with irrigation water quality and gypsum application. Saline irrigation water caused the B horizon to become waterlogged in winter months, while less saline irrigation water caused a perched watertable to develop, due to a dispersed Bt1 horizon. Application of gypsum reduced the soil Eh particularly in the A2 horizon (+500 to +50 mV) during winter. Thus redox potential can be influenced by irrigation water quality and gypsum applications.

Chapter 11 incorporated site data from the Barossa Valley non-irrigated site into a predictive mathematical model, TRANSMIT, a 2D version of LEACHM. This model was used to predict zones of gypsum accumulation during long-term irrigation (67 years). When applied over the entire soil surface, gypsum accumulated at 60 to 90 cm from the dripper in the B horizon; higher application rates caused increased accumulation. When applied immediately beneath the irrigation dripper, gypsum accumulated in a ‘column’ under the dripper (at 0 to 35 cm radius from the dripper), with very little movement away from the dripper. Also, the zone of accumulation of salts from high and low salinity irrigation water was investigated. These regions were found to be similar, although concentrations were significantly lower with low salinity water. In low rainfall years salts accumulated throughout the B horizon (35 – 150 cm), while in periods of high rainfall (and leaching) the A, A2 and Bt1 horizons (0 – 60 cm) were leached, although at greater depths (80 – 150 cm) salt concentrations remained high.

Chapter 12 summarises results and provides an understanding of soil processes in drip irrigated soils to underpin improved management options for viticulture. This study combines results from redox and soil solution monitoring, mineralogy, elemental gains and losses, and seasonal soil sampling to develop a mechanistic model of soil processes, which was combined with computer modelling to predict future properties of the soil. Major conclusions and recommendations of this study include:

- Application of saline irrigation water to soil then ameliorated with gypsum - The first application of gypsum was leached by the subsequent irrigation from extended regions of the soil. As Na continues to enter the system via irrigation water, gypsum needs to be regularly applied. Otherwise calcium will be leached through the soil and SAR increases.
- Application of non-saline irrigation water to soil then ameliorated with gypsum – The soil was found to only require one application at 8 tons/ha as this reduced SAR sufficiently. As less salt is entering the soil, subsequent gypsum applications can be at a lower rate or less frequently than required for saline irrigation water.
- Gypsum applied directly beneath the dripper systems distributes calcium to a narrow region of the soil, while large regions of the soil require amelioration (high SAR) and are not receiving calcium. Therefore, gypsum application through the drip system or only beneath the dripper should be combined with broad acre application.
- A range of methods to sample vineyards is recommended for duplex soils, including the use of saturation extracts, sampling time, sampling location (distance from dripper) and depth of sampling.

This work is critical for vineyard management and may be applicable to other Australian viticulture regions with Red Brown Earths.