University of Southern Queensland

Faculty of Engineering and Surveying

Soil chemistry equilibrium as influenced by solution volume and concentration

A dissertation submitted by

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In fulfilment of the requirements of

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Towards the degree of

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Abstract

The aim of this project was to investigate the effect of Electrical Conductivity (EC) and increasing Pore Volumes (PV) on soils solid and solution chemical equilibrium by analysis of soil leachate.

This is in order to understand:

1. The effect of EC on the rate chemical equilibrium is attained.
2. The number of PV's required to reach chemical equilibrium in soils with vastly different properties.

Three soils were studied by percolating solutions of varying EC (0.5, 1, 2, 4 and 8 dS/m) through soil cores and collecting the leachate. The leachate was analysed using an AAS for sodium, magnesium and potassium concentrations, along with testing for EC and determining HC.

From experimental investigation, it was observed that increasing the EC of the percolating solution increased the amount of cations replaced in the soil per PV. Furthermore, the rate of ion exchange generally decreases as the number of PV's increases.

Processes such as exchange models (diffusion or mass transfer), interlayer collapse from 2:1 clays, and macropore preferential flow Vs. micropore flow effects on exchange were considered, but require further investigation.

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CERTIFICATION

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Travis Wieck
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Signature

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Date

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To Dr Friedrike Eberhard and Raed Mahmood, thank you for your supervision and assistance in the laboratories, without this I would have no results to present in this dissertation.

For allowing me to take a couple hundred kilograms of his irreplaceable black soil, I must thank Gavin Norgaard.

To my family, the biggest thanks and heartfelt gratitude, for your support and encouragement to keep going over this long journey has ensured I'm writing this today.

To Sheree, thanks for being patient with me over the last few weeks.

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1. Introduction

As the demand for food and fibre increases, so too does the demand for irrigation water, which has seen a move towards the use of lower quality, saline-sodic waters to ensure food security (Ezlit *et al.* 2010). These waters have historically been avoided for irrigation, due to the potential of exacerbating salinity and sodicity within soil systems. Concerns for salinity effects are primarily related to plant salt toxicity levels and plant available water content, while sodicity concerns are related to reduction of soil hydraulic conductivity. However, Quirk and Schofield (1955) have shown that such waters can be used as irrigation water sources dependent on a soils threshold electrolyte concentration (TEC). The TEC is the required electrolyte concentration (directly proportional to electrical conductivity, EC) required to maintain a soil in a stable state at a given sodium adsorption ratio (SAR).

It is usual to determine soil TEC in the laboratory environment, in order to subject soil columns to subsequent decreasing water qualities, allowing the threshold EC to be determined. This threshold EC is defined as an arbitrary decrease in soil relative hydraulic conductivity between 10 and 25% (Cook *et al.* 2006; McNeal and Coleman 1966; Quirk and Schofield 1955). Bennett and Raine (2012) maintain soil columns at a range of ECs (0.5 to 8 dS/m) and subject them to ten consecutive solution applications of increasing SAR (0 to infinity). A major assumption of this method is that the soil ionic species composition of the cation exchange capacity (CEC) has equilibrated with the ionic species concentration of the percolating solution. If equilibrium has not been reached prior to application of the subsequent SAR solution, then it is possible that relative changes in soil hydraulic conductivity may be underestimated. Thus the impact of sodic water on the permeability of soils would be similarly underestimated.

1.1. Project Aim and Objectives

The aim of this project is to investigate the effect of Electrical Conductivity (EC) and increasing Pore Volumes (PV) on soils solid and solution chemical equilibrium by analysis of soil leachate.

This is in order to understand:

3. The effect of EC on the rate chemical equilibrium is attained.
4. The number of PV's required to reach chemical equilibrium in soils with vastly different properties.

This will be achieved by conducting a literature review, designing an experimental methodology and analysing results obtained in order to understand the above objectives.

The Project Specification can be found in Appendix A.

1.2. Dissertation Overview

1.2.1. Literature Review

A literature review will be conducted in order to understand various processes and phenomenon that govern chemical equilibrium in soils. Firstly, the relationship between salinity and sodicity will be introduced and then parameters to measure these will be discussed. Secondly, ion exchange processes will be investigated by exploring a modified Guoy-Chapman model of the Diffuse Double Layer (DDL) and the mechanics of ion exchange. Thirdly, the TEC will be discussed in more detail. Finally, factors affecting the kinetics of soil chemical processes, including clay mineralogy, ion charge and radius and temperature, will be explored and some literature investigating chemical equilibrium prediction will be introduced.

1.2.2. Experimental Methodology

This section will detail soil selection, preparation and initial chemical analysis. It will then introduce how soil cores were prepared, how the $CaCl_2$ solutions were prepared and how the experiment was set up to obtain the leachate in pore volumes (PV's). Methods of analysis and instruments used will be discussed and statistical analysis methods detailed.

1.2.3. Results

Results of ion exchange curves for sodium, magnesium and potassium, electrical conductivity (EC) and hydraulic conductivity (HC) will be presented in graphs.

1.2.4. Discussion

The discussion will consider the effect of percolating solution strength on ion exchange, soil pre volumes required to leach to effect chemical equilibrium, the relationship between steady state hydraulic conductivity and chemical equilibrium and the appropriateness of leachate electrical conductivity as an indicator for soil chemical equilibrium. Finally, recommendations for future work will be discussed.

1.2.5. Conclusions

In this section, conclusions as to the effectiveness of this project compared to the initial aims and objectives will be made.

2. Literature Review

This literature review explores the various processes and phenomena that impact on the ionic exchange processes responsible for equilibrium between soil solid and liquid phases. Firstly, the concepts of salinity and sodicity will be introduced and various parameters used to define them will be defined. Secondly, the relationships between the soil and soil solution, and the process of adsorption will be discussed. Finally ion exchange processes and kinetics of soil chemical processes will be introduced in order to understand how soil solid and liquid phases equilibrate.

2.1. Salinity and sodicity

Ghassemi *et al.* (1995) define salinity as the concentration of dissolved mineral salts in water and soil-water as a unit of volume or weight basis. In regions of Australia where the climate is semi-arid, insufficient precipitation percolating through soils can lead to decreased leaching of soluble salts from the soil. Sparks (2003) concludes that the majority of saline soils occur due to the presence of chloride (Cl^-), sulfate (SO_4^{2-}) and/or nitrate (NO_3^-) in the soil aqueous phase. However, Rengasamy and Olsson (1991) attribute the majority of Australian salinity to high concentrations of sodium chloride (NaCl) within semi-arid environments. As soil salinity increases, so too does the potential for reduced plant growth and even plant death, due to increases in the soil solution osmotic potential (Tanji 1990).

Traditionally, sodicity has been a term without any one agreed numeric threshold definition. Worldwide sodic thresholds have been defined as an exchangeable sodium percentage (ESP) between 5 and 15 for Vertosols in India (Kadu *et al.* 2003), an ESP of 40 on the Indo-Gangetic Plains in India (Abrol and Fireman 1977) or an ESP of 15 suggested by the United States Department of Agriculture (Soil Survey Staff 1999). Within Australia, the most widely used sodic threshold definition used is that of Northcote and Skene (1972), who propose that a soil is sodic if it has an ESP greater than 6. This disparity of numeric definition is due to the many variables that factor into determination of the sodic nature of a soil.

The main factors influencing soil sodicity are soil type (Quirk and Schofield 1955), clay type and content (Frenkel *et al.* 1978), pH of the soil solution (Suarez *et al.* 1984; Sumner 1993), method of application of irrigation water (Ezlit 2009), initial water content of the soil (Dehayr and Gordon 2005) and organic matter (Nelson and Oades 1998). For the purpose of discussing sodicity in a global context, this literature review considers the non-numeric definition provided by Anon (1979) to be the most useful: “a non-saline soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure under most conditions of soil and plant type”. Although, that is not to say a soil cannot be both saline and sodic.

Soils that exhibit both sodic and saline properties are termed saline-sodic soils. Sumner (1993) suggests that saline-sodic soils are particularly difficult to manage as any leaching of salts can reduce the electrolyte concentration below a critical level (i.e. the TEC), making the soil prone to dispersion. Kemper *et al.* (1974) describe how in situations with low electrolyte concentrations in the soil solution, osmotic forces pull water into the diffuse layer of adsorbed ions, effectively increasing the thickness of the diffuse double layer (DDL) (discussed later in this review in section

2.4.1). The opposite occurs where there is a high electrolyte concentration: osmotic forces pull water into the soil solution, reducing the thickness of the DDL and helping to maintain a stable soil.

Rengasamy *et al.* (1984a) and McKenzie and Murphy (2005) have illustrated that ESP and EC together produce a matrix of dispersion effects, rather than ESP being the single determinant of a soils dispersive behaviour. Figure 2.1 shows the matrix of effects, from dispersive soils to potentially dispersive soils to flocculated soils for a Red Brown Earth (Chromosol). If we consider an ESP of 20, an EC of 0 to 0.15 dS/m will result in dispersion, whereas if the EC of the solution is increased to at least 1.6, the soil will remain flocculated and maintain its stable structure. If the EC is somewhere between 0.15 and 1.6 dS/m, the soil is classified as potentially dispersive dependant on other factors.

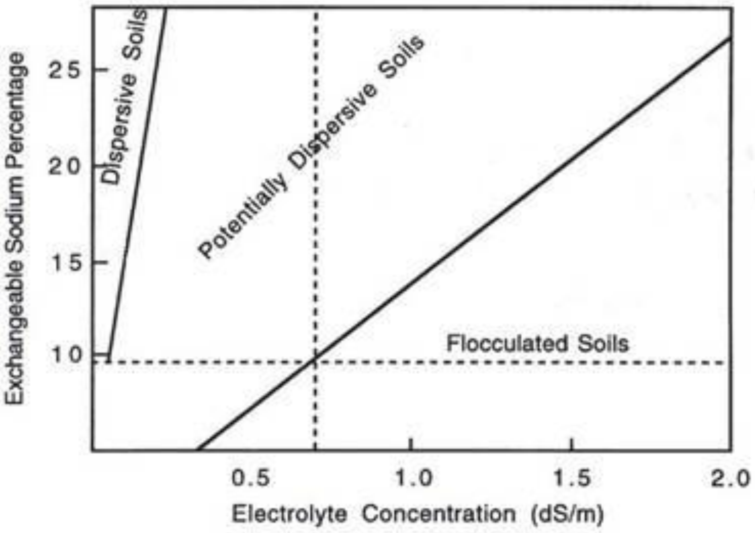

Figure 2.1 Chart for dispersive soil classification, adapted from (Rengasamy *et al.* 1984b) to show EC and ESP rather than total cation concentration (TCC) and sodium adsorption ratio (SAR).

Importantly, the tolerance of soil stability to EC and sodium adsorption ratio (SAR) solutions differs between soils (Bennett and Raine 2012; Ezlit 2009; McNeal and Coleman 1966; Quirk and Schofield 1955), the extent to which depends on a threshold electrolyte concentration (TEC), discussed in further detail later in this review. Furthermore, Sumner (1993) states that even non-sodic soils have been known to disperse if the soil solution is sufficiently low in electrolytes, which is once again a function of the TEC of a particular soil.

2.2. Important sodicity and salinity parameters

This section defines the important soil parameters and their equations that are used to measure and describe the effects of water salinity and sodicity on soil structural form.

2.2.1. Exchangeable Sodium Percentage (ESP)

ESP is the measure of exchangeable Na^+ in the cation exchange capacity (CEC) of the soil; i.e. it is the ratio of exchangeable Na^+ adsorbed to a clay face with the clay faces total capacity to adsorb cations (Equation 2.1).

$$ESP = \frac{[Na_{ex}]}{CEC} \times 100 \qquad \text{Eq 2.1}$$

where CEC is the net negative charge of the clay exchange ($cmol_c.kg^{-1}$), which is approximately equal to the sum of base exchangeable cations: Na_{ex}^+, Ca_{ex}^{2+}, Mg_{ex}^{2+}, K_{ex}^+, and Al_{ex}^{3+} (Sumner 1993).

The importance of ESP to soil stability varies according to different soil mineralogies, electrolyte concentrations and organic carbon levels (Valzano 2000).

2.2.2. Sodium Adsorption Ratio (SAR)

The SAR is the relative proportion of Na^+ to the divalent ions (Ca^{2+} and Mg^{2+}) in solution (Equation 2.2).

$$SAR = \frac{[Na^+]}{[Ca^{2+} + Mg^{2+}]^{1/2}} \qquad \text{Eq 2.2}$$

The cation concentrations are measured in $\text{mmol}_c.\text{L}^{-1}$ in the solution phase.

SAR is used to describe the relative sodicity potential of irrigation water. ESP cannot be used to describe this because negatively charged exchange sites do not exist within solution.

2.2.3. ESP-SAR Relationship

Soil ESP is influenced by the SAR of the soil solution and changes in the SAR cause changes in the ESP of the soil it is passing through (Valzano 2000). Relationships between ESP and SAR for a red-brown earth have been investigated by Rengasamy *et al.* (1984b); they showed that the relationship between ESP and SAR for a red-brown earth using a 1:5 soil to water solution was described by (Equation 2.3):

$$ESP = 1.95\, SAR_{1:5} + 1.8 \qquad \text{Eq 2.3}$$

Relationships between soil ESP and SAR may change depending on the initial soil pH and the pH at which the cation exchange capacity is estimated (Valzano 2000). Sumner (1993) showed that the greater the differences in the pH values, the greater the difference between ESP and SAR. Studies by Johnston (1975) and Burrow *et al.* (1998), working with different soil types, have obtained very different relationships to the one above, proving that it is highly unlikely one rule can be used to define the relationship between ESP and SAR.

2.3. Ion exchange processes

Ion exchange in soils is a reversible process in which cations and anions are exchanged between solid and liquid phases or solid and solid phases (if in close proximity to one another) (Sposito 1989). Ion exchange processes involve the adsorption of ions onto colloidal surfaces or desorption of ions from these surfaces (Toth 1964). Ion exchange influences various soil characteristics and behaviour, including swelling and shrinkage, leaching of electrolytes, weathering of minerals and adsorption of nutrients by plants (Wiklander 1964) and occurs almost entirely in the clay and silt fractions, as well as within the organic fraction (Valzano 2000).

Ion exchange capacity is the sum of the CEC and the anion exchange capacity (AEC). The CEC is the amount of cations that can be adsorbed, in an exchangeable fashion, on the negative charge sites of the soil, whereas the AEC is the sum of total exchangeable anions that a soil can adsorb (Soil Science Society of America 1997).

The CEC of a soil determines the capacity of a soil to retain ions in a form available for plant uptake and not susceptible to leaching in the soil profile (Sparks 2003).

2.3.1. The diffuse double layer (DDL)

The Guoy-Chapman DDL theory (or modifications of) is often used to describe the spatial distribution of counterions in the DDL (Valzano 2000). The DDL influences soil physical characteristics such as dispersion, flocculation and swelling. Figure 2.2 illustrates the layout of the DDL, showing the negatively charged clay tactoid, the positively charged layer immediately adjacent to the clay tactoid and the exchangeable ions surrounded by water, further out from the negatively charged tactoid (Wiklander 1964).

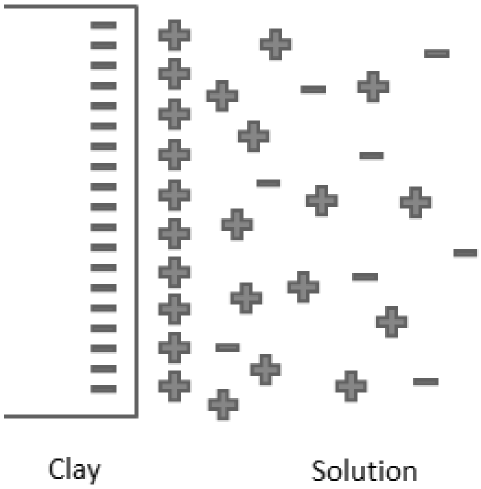

Figure 2.2 Diffuse electric double layer model according to Gouy (van Olphen 1977).

The Gouy-Chapman DDL theory is far from perfect, as it is less applicable to more complicated processes such as ion to ion interactions, divalent or multivalent cations (McBride 1994), tactoids/quasi-crystals (Russo and Bressler 1977; Shainberg *et al.*

1971), the forces involved with clay swelling (Viani *et al.* 1983) or the impacts of hydration of the exchangeable cations (Pashley 1981; Sposito 1983). However for the purposes of this literature review, the Gouy-Chapman model will be considered adequate in explaining ion exchange processes.

The distance at which counterions are located from a colloidal surface is inversely proportional to the soil solution concentration and to the square of the valency of the neutralising solution (Sposito 1989). This phenomena is partly predicted by the Schulze-Hardy rule, in that divalent ions have a greater propensity to be attracted to the particle surface than monovalent ions (Bolt 1955). Theoretically, this should result in a more compacted DDL, owing to the reduced number of cations needed to neutralise the negatively charged clay tactoid.

The valency of cations in the DDL and the solution play an important role in the size of the DDL and structural stability of soils. Monovalent cations (Na^+ and K^+), require twice as many ions in the colloid exchange sites to neutralise the negative charge of the exchange sites, than divalent cations (Ca^{2+} and Mg^{2+}). Sumner (1993), Narasimha and Mathew (1995), and Shainberg and Levy (2005) show that a Ca^{2+}-dominated DDL will generally be more compressed than a Na^+-dominated DDL, resulting in a soil that is more difficult to disperse, due to greater Coulombic attractive forces between adjacent colloidal particles. This concept is shown in Figure 2.3 using sodium and calcium as example exchangeable cations.

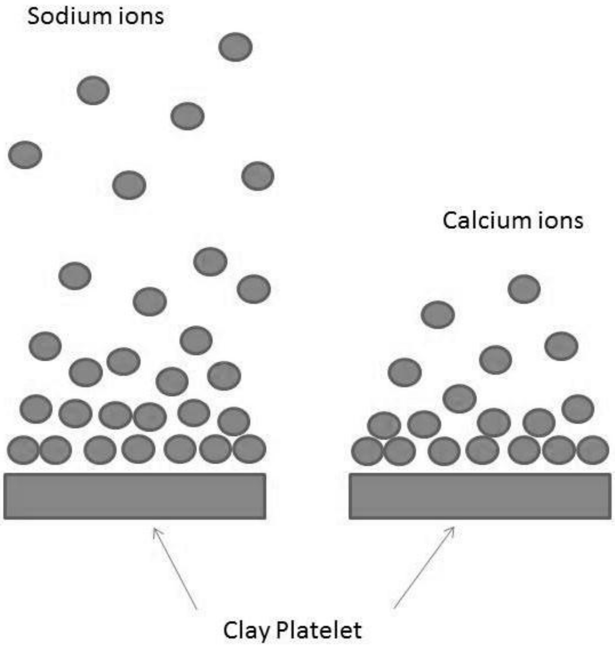

Figure 2.3 Behaviour of sodium and calcium attached to clay particles (Hanson *et al.* 1999).

Another ionic property impacting on the size of the DDL is the hydrated radius of an ion in solution. A larger hydrated radius will result in a more diffused DDL to achieve the required electroneutrality (Sparks 2003). Table 2.1 below gives some details regarding the four main cations investigated in this project; Na^+, K^+, Ca^{2+} and Mg^{2+}. From this data it can be seen that for monovalent cations, a hydrated potassium ion is larger than a hydrated sodium ion, while for divalent cations, a hydrated magnesium ion is larger than a hydrated calcium ion.

Table 2.1 Ionic radii for selected cations of interest in this investigation (Evangelou and Phillips 2005).

	Ionic radii (Å)	
Ion	*Not hydrated*	*Hydrated*
Na^+	0.98	7.9
K^+	1.33	5.32
Mg^{2+}	0.89	10.8
Ca^{2+}	1.17	9.6

The effects of valency and hydrated radius on ion exchange selectivity in soils is summarised in the lyotropic series. This is a measure of the relative ability of ions to replace one another during ionic exchange processes and is usually given as below for soils (Helfferich 1962):

$$Al^{3+} > Ca^{2+} > Mg^{2+} > K^{+} = NH_4^{+} > Na^{+}$$

From this series, it can be noted that if two cations have the same valence, the ion with the smallest hydrated radius is preferred, resulting in a soil that is less prone to dispersion. The differences in resistance to dispersion between calcium and magnesium dominated systems has been extensively researched (Dontsova and Norton 2002; Emerson and Chi 1977; Levy *et al.* 1988; Rengasamy *et al.* 1986). All these researchers have concluded that a magnesium-dominated soil is easier to disperse than a calcium-dominated soil, attributed to the larger hydrated radius of magnesium ions contributing to a larger DDL.

2.3.2. Mechanics of ion exchange

Boyd *et al.* (1947) were the first to clearly show that ion exchange is diffusion controlled. They also discovered that the reaction rate is limited by mass-transfer phenomena that are either film diffusion (FD) or particle diffusion (PD) controlled.

Specific transport processes in a soil-solution system, shown in Figure 2.4 below, include (1) transport in the soil solution, (2) transport across a liquid film at the particle/liquid interface (FD) (3) transport in liquid filled macropores (PD), (4) diffusion of a sorbate at the surface of the solid (PD) (5) diffusion of a sorbate occluded in a micropore (PD) and (6) diffusion in the bulk of the solid (Aharoni and Sparks 1991).

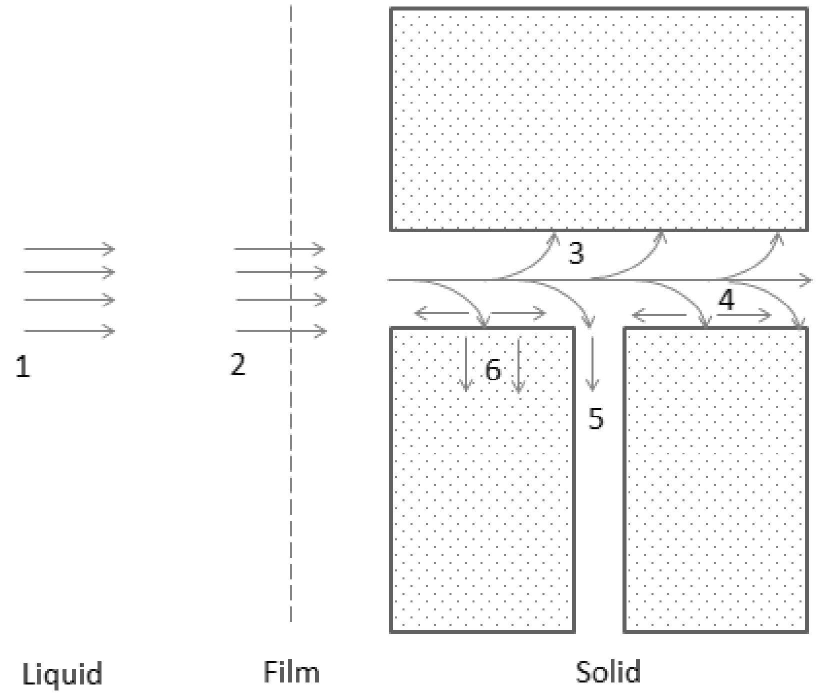

Figure 2.4 Transport processes in solid-liquid soil reactions (Aharoni and Sparks 1991). Arrows represent transport processes in a soil-solution system.

2.4. Threshold electrolyte concentration

The threshold electrolyte concentration (TEC) is the electrolyte concentration (EC) at which a soil will remain stable subject to infiltration with a given SAR solution without practically limiting dispersion (Bennett and Raine 2012; McNeal and Coleman 1966; Quirk and Schofield 1955). The particular TEC boundary is somewhat arbitrary in that structural decline is induced to some extent as sodium increases in the soil system; i.e. there is no black and white boundary. Hence, a practically manageable percent decline in hydraulic conductivity is used to define the

TEC for a particular soil. Quirk and Schofield (1955) used a value of 10 to 15% reduction in permeability as the point at which the TEC had been reached, while McNeal and Coleman (1966) later suggested a value of 25% reduction in permeability. Another study, undertaken by Cook *et al.* (2006), proposed the adoption of a 20% reduction in permeability as the TEC value. Bennett and Raine (2012), using 20% reduction in saturated hydraulic conductivity (K_{sat}), showed that even soils within the same order, with similar properties, can have drastically different TEC curves (Figure 2.5).

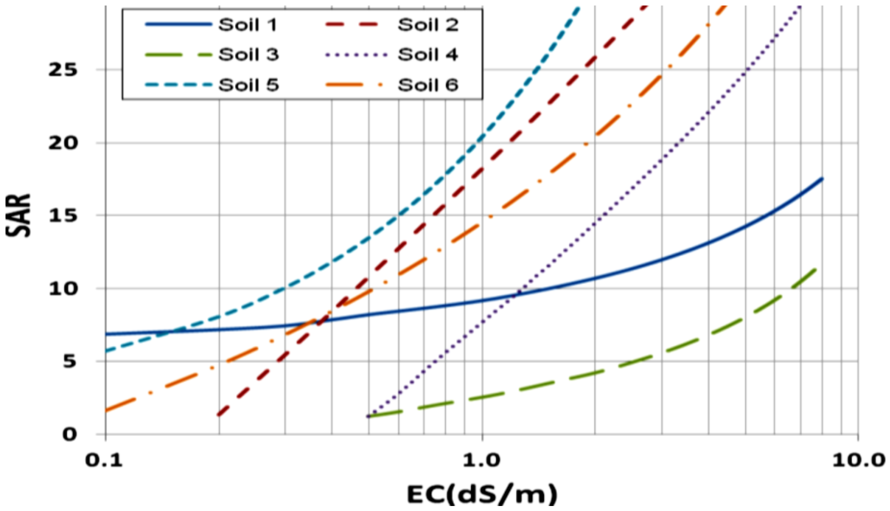

Figure 2.5 Comparison of the TEC (20% reduction in K_{sat}) curves for six soils (Bennett and Raine 2012). Soils 1, 2 and 6 are Vertosols and 3, 4 and 5 are Chromosols.

In preparing a soil for analysis to determine its TEC curve, soil cores are flushed with a calcium solution ($CaCl_2$) pre-treatment to establish chemical equilibrium throughout the soil core before further experimentation takes place. In their recent research, Bennett and Raine (2012) used a pre-treatment volume of 1000 cm^3 to obtain soil exchange equilibrium, prior to changing solution EC to obtain the TEC curves.

2.5. Kinetics of soil chemical processes

With the exception of some soil chemical reactions, ion exchange kinetics are usually very rapid, occurring on millisecond time scales (Sparks and Zhang 1988; Tang and Sparks 1993). The rates of these reactions are influenced by the type of soil component (Sparks 2003), ion charge and radius (Helfferich 1962) and temperature (Bunnett 1986).

2.5.1. Soil components

Clay mineralogical composition is widely considered to be one of the most important factors affecting rates of ion exchange in soils (Sparks 1988; Sparks 2003). An example of this is sorption reactions on clay minerals such as kaolinite and smectite are often more rapid than on vermiculite and micaceous minerals (Sparks 2003). This is largely due to the differences in physical structures of the clays with Figure 2.6 showing the differences between kaolinite, montmorillonite and vermiculite clays on the rate of potassium adsorption.

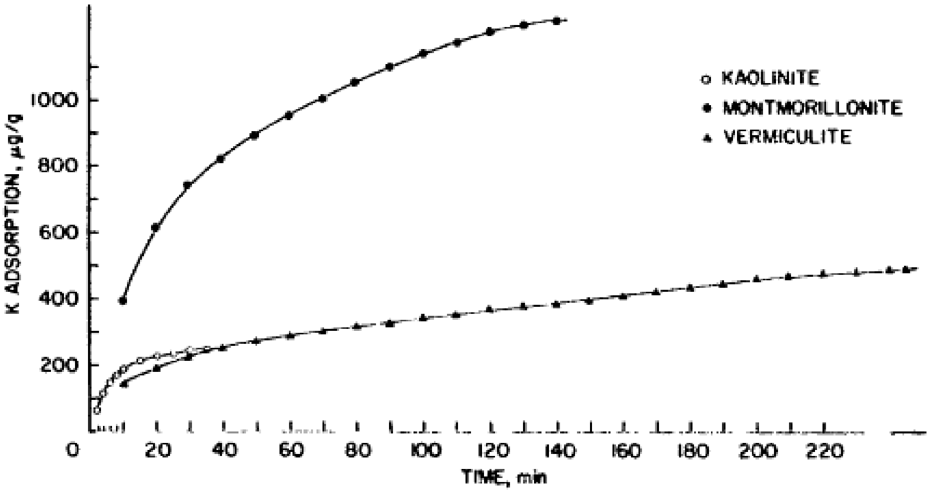

Figure 2.6 Potassium adsorption versus time for kaolinite, montmorillonite and vermiculite clay minerals (Jardine and Sparks 1984).

Rates of ion exchange processes on kaolinite and smectite are usually quite rapid. Kaolinite has readily available planar external surface sites due to the strong hydrogen bonding between adjacent tetrahedral clay sheets, allowing rapid exchange on the external sites (Sparks 1988; Sparks 2003). While with smectite, weaker bonds between sheets allow ions in solution to penetrate the interlayer space, promoting rapid exchange as the ions in solution can access exchange sites on the surfaces of the clay sheets (Sparks 1988; Sparks 2003).

Vermiculite and micas have multiple exchange sites including planar, edge and interlayer sites (Sparks 2003) and rates of ion exchange are usually quite slow. With these clay components, ion exchange can involve 2 to 3 different reaction rates: high rates on external sites, intermediate rates on edge sites and low rates on interlayer sites (Comans and Hockley 1992; Jardine and Sparks 1984). Low exchange rates on interlayer sites are evidence of partial to total collapse of the space between clay sheets and as a consequence, sorption and desorption processes in this space are interparticle diffusion and mass transfer controlled (Sparks 2003).

2.5.2. Ion charge and radius

The charge of an ion has a significant effect on diffusion rates through an ion exchanger such as a resin (Helfferich 1962). Generally, the rate of exchange decreases as the charge of the exchanging species increases (Sparks 1988). Sharma *et al.* (1970) studied the exchange rates of Cs^+, Co^{2+} and La^{3+} in H^+, Ca^{2+} and La^{3+} systems, revealing that the interdiffusion coefficient decreased rapidly as the ionic charge increased. Furthermore, it was observed that the interdiffusion coefficient decreased as the charge of the other ion increased.

However Sparks (2003) writes that the exchange rates of monovalent ions such as K^+, NH_4^+ and Cs^+ are often slower than divalent ion such as Ca^{2+} and Mg^{2+}. This is related to the smaller hydrated radius of the monovalent ions, allowing them to fit well in the interlayer spaces between clay sheets, causing partial or total interlayer collapse. This causes the ion exchange processes to slow down and interparticle diffusion and mass transfer to be the controlling exchange processes (Sparks 2003).

2.5.3. Temperature

Increasing temperature usually causes a marked increase in reaction rate (Bunnett 1986). Arrhenius observed the relationship (Equation 2.4) between temperature (T) and reaction rate constant (k) to be:

$$k = Ae^{-E/RT} \qquad \text{Eq 2.4}$$

where A is a frequency factor, E is the energy of activation and R is the universal gas constant (Sparks 1988).

Low E values usually indicate diffusion controlled processes whereas higher E values indicate chemical reaction processes (Sparks 1985; Sparks 1986). Huang *et al.* (1968) researched the effect of temperature on the rate of potassium release from potassium-bearing minerals. They concluded that a 10 K rise in temperature during the reaction period resulted in a two to three-fold increase in the rate constant.

Evans and Jurinak (1976) investigated the rate of phosphorous release as a function of temperature. During the initial four hours of the reaction, the effect of temperature was significant, although the rate increase was only slight as temperature increased from 11 to 40 ºC; at durations greater than four hours, the effect of temperature was insignificant.

2.6. Equilibrium Prediction

Shackelford *et al.* (1999) investigated the factors affecting the applicability of EC breakthrough curves as an indicator of chemical equilibrium between effluent and influent solutions. EC breakthrough occurs when effluent EC is normalized with respect to influent EC (Shackelford and Redmond 1995). Their comparisons between theoretically predicted and measured breakthrough curves varied from good to excellent, with results indicating that chemical equilibrium cannot be attained before complete EC breakthrough is attained.

Figure 2.7 shows the measured and predicted EC breakthrough curves comparing measured data from Shackelford and Redmond (1995) with theoretically predicted curves from Shackelford *et al.* (1999). The theoretical curves tend to slightly underpredict the measured curves because no exchangeable cations were measured in the effluent from the test and a formula that did not account for the electroneutrality constraint had to be used.

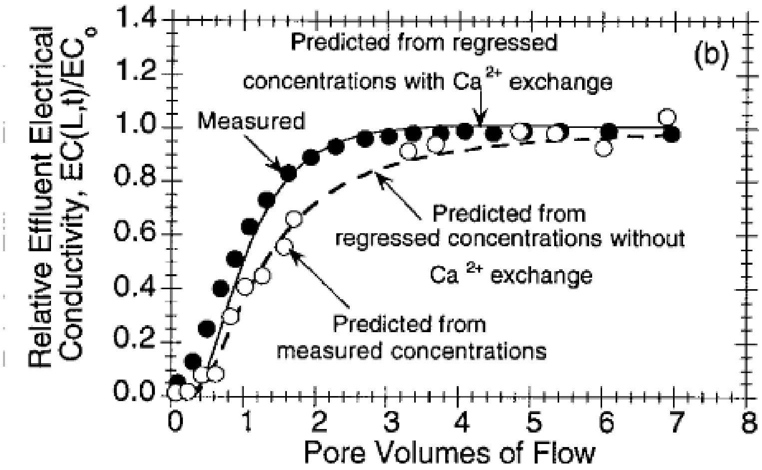

Figure 2.7 Measured and predicted EC breakthrough curves (Shackelford *et al.* 1999).

Recent research from Reading *et al.* (2012) used EC, chemical analysis of leachate and hydraulic conductivity as means to predicting attainment of chemical equilibrium in a strongly sodic Vertosol from North Queensland. They used the constant head method to test when chemical equilibrium was attained by flushing a saturated gypsum solution through repacked soil cores at 2 bulk densities (1.3 g/cm^3 and 1.4 g/cm^3). The EC trends were identical for both densities (Figure 2.8), in that the measured EC of the effluent matched that of the applied solution after approximately 15 pore volumes. The stable EC beyond the 15 pore volumes suggests that chemical equilibrium had been attained, as proposed by Shackelford *et al.* (1999).

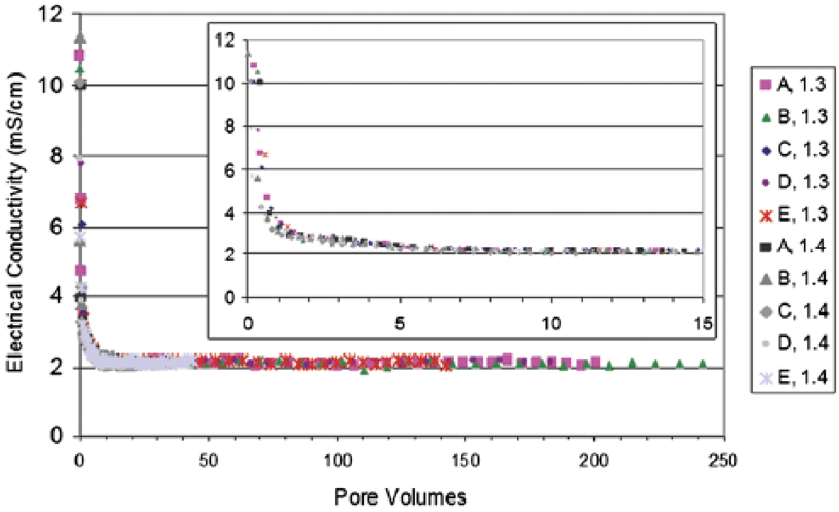

Figure 2.8 Electrical conductivity of the leachate solution as a function of pore volumes, for two soil bulk densities where A-E represent replicate columns (Reading *et al.* 2012).

In both tests, the sodium concentration in leachate solutions reduced from 1000 mg/L to less than 10 mg/L after 15 pore volumes and less than 2 mg/L after 25 pore volumes (Figure 2.9). After the high initial flushing rate of sodium, the calcium began to replace magnesium and the concentration of magnesium increased in the leachate (Figure 2.10). The magnesium concentration in the effluent approached minimal concentrations at around 50 pore volumes for all leachate solutions. Potassium was not considered in this study.

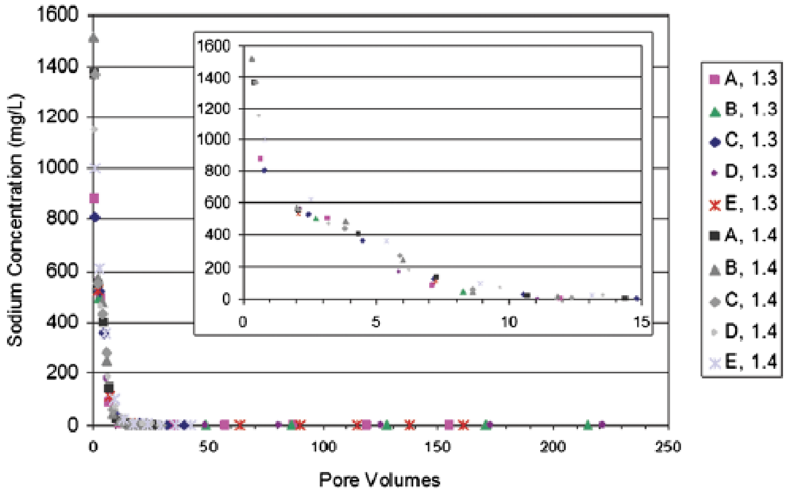

Figure 2.9 Sodium concentration in the leachate solutions as a function of pore volumes, for two soil bulk densities, where A-E represent replicate columns (Reading *et al.* 2012).

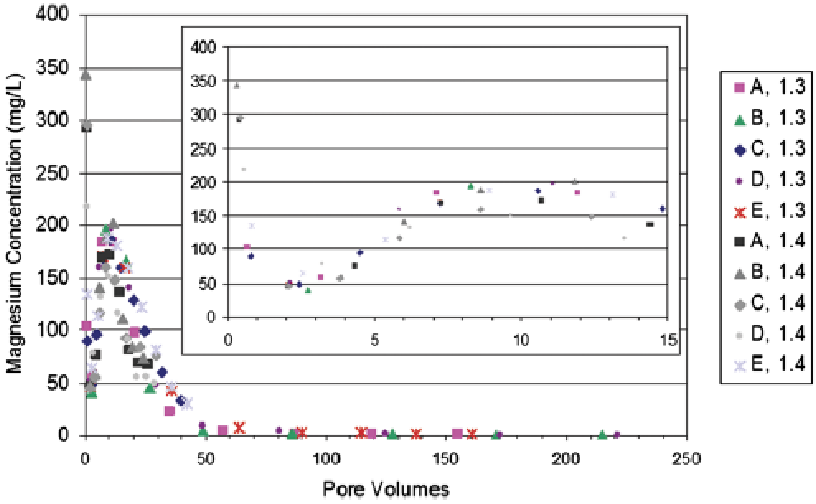

Figure 2.10 Magnesium concentration in the leachate solutions as a function of pore volumes, for two soil bulk densities, where A-E represent replicate columns (Reading *et al.* 2012).

Bulk density had a large impact on the number of pore volumes required for the hydraulic conductivity to approach steady state. The cores packed at 1.4 g/cm^3 approached a stable flow rate after 25 to 45 pore volumes had passed through over a period of 3 weeks (Figure 2.11). For the 1.3 g/cm^3 cores, 150 to 250 pore volumes of solution were applied before the flow rate stabilized (Figure 2.12).

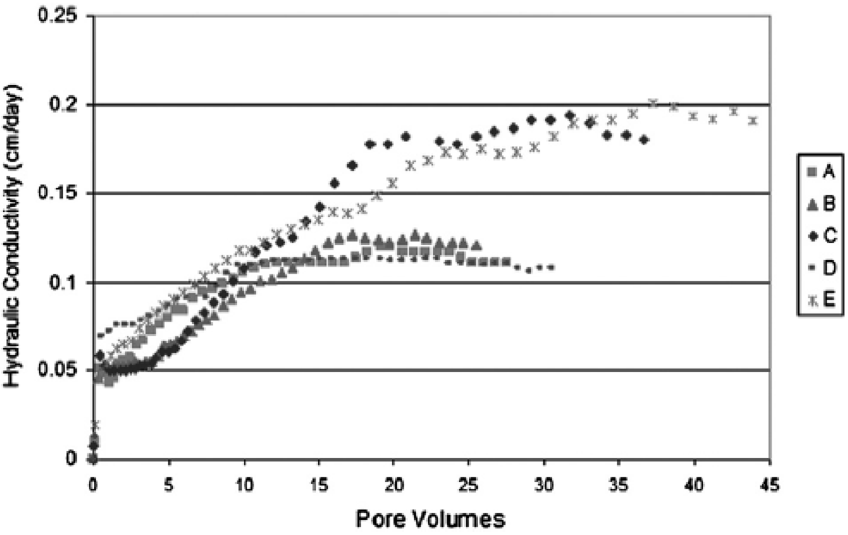

Figure 2.11 Hydraulic conductivity responses to the application of a saturated gypsum solution to soil columns packed to a bulk density of 1.4 g/cm3, as a function of pore volumes collected, where A-E represent replicate columns (Reading *et al.* 2012).

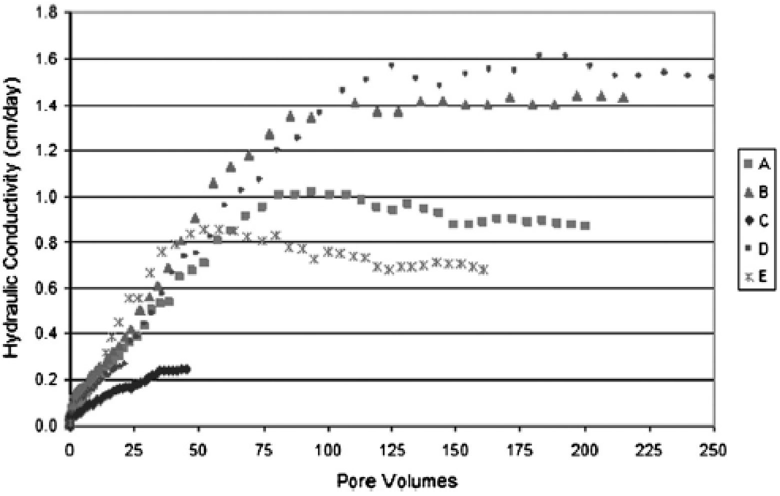

Figure 2.12 Hydraulic conductivity responses to the application of a saturated gypsum solution to soil columns packed to a bulk density of 1.3 g/cm3, as a function of pore volumes collected where A-E represent replicate columns(Reading *et al.* 2012).

Reading *et al.* (2012) concluded that a lower bulk density increased the accessibility of exchange surfaces, contributing to a greater proportion of the exchangeable cations, especially magnesium, in the soil being replaced by calcium from the applied solution. This resulted in the lower bulk density soil reaching chemical equilibrium at a faster rate.

2.7. Conclusions

Chemical equilibrium is a difficult phenomenon to predict in regards to soil chemistry. Ion exchange processes taking place in the DDL are complex and highly dependent on soil properties and the environmental conditions in which the reactions are taking place. Differences between soils and conditions, including clay mineralogy, charge of the exchanging ion, hydrated radius of the exchanging ion and temperature, are likely to impact on the rate at which soils attain chemical equilibrium.

In order to fully understand the complete effects of low quality irrigation water on soil chemistry, TEC analysis must be performed. As part of this process the soil core must reach chemical equilibrium with the $CaCl_2$ pre-treatment solution prior to flushing with NaCl. If this is not reached, the impact of the TEC analysis may be overestimated, hence underestimating the impact of low quality irrigation water on soil permeability.

3. Experimental Methodology

The purpose of this project was to understand the number of PV's required to reach chemical equilibrium in soils with vastly different properties and to understand the effect of EC on the rate chemical equilibrium is attained. The entirety of this project was laboratory based, and the methodologies and procedures employed during this project are detailed in this section of the report.

3.1. Soil Selection

Three soils were chosen to test the effects of increasing EC and PV on the rate of attainment of chemical equilibrium; a Red Ferosol, Black Vertosol and a Brown Tenosol. The three soils were chosen on the basis of differing properties and soil order. These soils are common to the Darling Downs. A further motivation is the interest in the use of such soils for land application of treated CSG water.

A Black Vertosol is a fine structured soil with high 2:1 clay content. They tend to develop large cracks when dry and swell when wet (CSIRO 2007c). They are of particular interest to agriculture as they have high chemical fertility and water holding capacity, due to the mineralogical properties and high CEC.

A Red Ferosol is a medium structured soil with high amounts of free iron oxide contained in their B2 horizon (CSIRO 2007a). They also have good agricultural potential due to their good structure, good chemical fertility and water holding capacity. However, they are not dominated by a shrink swell capacity such as the Vertosol.

A Brown Tenosol is a coarse textured soil with low clay content and high sand content (CSIRO 2007b). They are not of particular importance to agriculture with their low chemical fertility, poor structure and low water holding capacity.

3.2. Soil sampling and preparation

Black Vertosol and Red Ferosol soil samples were collected from the top 100 mm of soil at their respective sites. The Brown Tenosol sample was obtained from the National Centre for Engineering in Agriculture (NCEA) soil library and consisted of 0–400 mm depth soil.

The Black Vertosol sample was collected from a dairy farm paddock at Yalangur, Queensland (27º 24; 58” S, 151º 49’ 27” E, 429 m elevation). Figure 3.1 shows a photo of the site where the sample was obtained and Figure 3.2 shows an image taken from Google Earth of the farm with the site the sample was taken.

The Red Ferosol sample was collected near the University of Southern Queensland Dam Evaporation trial site (27º 36’ 36” S, 151º 55’ 53” E, 691 m elevation). Figure 3.3 shows a Google Earth image of the site at the University showing where the sample was taken.

Figure 3.1 Photo of the site where the Black Vertosol sample was collected.

Figure 3.2 Google Earth image of farm at Yalangur where Black Vertosol sample was obtained. The orange star shows the exact location where the sample was taken from and the orange arrow shows north.

Figure 3.3 Google Earth image of University of Southern Queensland dam evaporation trial site where the Red Ferosol sample was taken. Orange start shows sample location and orange arrow shows north.

The Brown Tenosol was sampled from the Roma, Qld district during exploration for agricultural soils suitable to undergo irrigation with treated CSG water.

The three soils were spread out on black plastic matting to a depth of no more than 20 mm in an air-conditioned room to air dry. After a week of drying and periodic turning, the soil was crushed to pass a 2 mm sieve. Care was taken to not apply excessive energy during crushing so as to preserve soil structural form and reduce mechanical effects on soil dispersive potential.

3.3. Initial soil chemical analysis

The three soils were analysed to determine their chemical properties prior to leaching. Properties required for comparison include organic matter, EC, pH, CEC , exchangeable cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and total cations (Na^+, K^+, Ca^{2+}, Mg^{2+}). Results of analysis are presented in Table 3.1. Methodologies used to analyse soil samples are listed in Table 3.2.

Table 3.1 Initial soil chemical analysis of Red Ferosol, Black Vertosol and Brown Tenosol.

Measurement	*Units*	*Ferosol*	*Vertosol*	*Tenosol*
Organic Matter	%	3.9	3.2	0.9
EC	dS/m	0.09	0.06	0.03
pH		7.86	7.42	6.55
CEC	meq/100g	18.87	48.2	5.47
Exchangeable Na	meq/100g	0.32	1.59	0.05
Exchangeable K	meq/100g	0.46	1.04	0.87
Exchangeable Mg	meq/100g	3.02	18.4	3.52
Exchangeable Ca	meq/100g	15	27.1	1.03
Total Na	mg/kg	300	533	47
Total K	mg/kg	767	1900	912
Total Mg	mg/kg	1767	5767	320
Total Ca	mg/kg	3667	6433	637
Soil Moisture Content	%	3.61	4.82	1.5

Table 3.2 Initial soil chemical analysis methods.

Measurement	*Units*	*Testing method*
Organic Matter	%	R & L 6A1
EC	dS/m	R &L 3A1
pH		R & L 4A1
CEC	meq/100g	R & L 15D3
Exchangeable Na	meq/100g	R & L 15D3
Exchangeable K	meq/100g	R & L 15D3
Exchangeable Mg	meq/100g	R & L 15D3
Exchangeable Ca	meq/100g	R & L 15D3
Total Na	mg/kg or %	US EPA 3051
Total K	mg/kg or %	US EPA 3051
Total Mg	mg/kg or %	US EPA 3051
Total Ca	mg/kg or %	US EPA 3051
Soil Moisture Content	%	Black (1965)

R & L in the above table refers to soil testing methods found in Rayment and Lyons (2011). All testing procedures are further detailed in the following sections.

3.3.1. Method 6A1: Organic Carbon – Walkley & Black

This method uses the heat of reaction to oxidise organic carbon (OC), however may not discriminate between finely dispersed charcoal and soil organic carbon (SOC) (Rayment and Lyons 2011). Heat of dilution in this method raises the temperature to 110 – 120 ºC. The reaction is as follows:

$$2Cr_2O_7^{2-} + 16H^+ + 3C \rightarrow 4Cr^{3+} + 8H_2O + 3CO_2$$

In the absence of interference, the chromic ions (Cr3+) produced should be in reasonable proportion to the OC oxidised (Rayment and Lyons 2011).

A series of standards was prepared for each set of analyses by dispensing 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 mL of the Standard Sucrose Solution into 250 mL conical beakers. These standards contain 0 to 50 mg of C (0 to 5% for a 1 g soil sample and 0 to 25% for one 0.2 g soil sample. The standards were then evaporated in an oven not greater than 65 ºC and subsequently cooled to room temperature.

Samples of finely ground (< 0.5 mm), air-dry soil were weighed according to the expected C content. Soils were then transferred to 250 mL conical beakers. Either 10 mL of 0.5 M sodium dichromate or 10 mL of chromium trioxide was added and swirled gently to ensure all particles were wet. After swirling occasionally for 10 minutes, 20 mL of concentrated sulphuric acid was added over 10 to 15 seconds with gentle swirling. After a further 30 minutes with occasional swirling, 170 mL of reagent water was added and swirled to mix thoroughly. The whole beaker was then set aside to cool and for particles to settle.

After cooling, the samples were centrifuged if not already clear. Absorbance of the standards and samples was determined at 600 nm, with the reagent water set to zero. Samples were disposed of in an environmentally responsible manner, as Cr is a toxic heavy metal.

3.3.2. Method 3A1: EC of 1:5 soil/water extract

This method determines the EC of a soil based on a 1:5 (w/v) soil/water extract with air-dry soil (Rayment and Lyons 2011).

A 1:5 (w/v) soil/water suspension was prepared and mechanically shaken end-over-end at 25 ºC in a closed system for 1 h. This was allowed to settle for a minimum of 20 to 30 minutes. EC measurements were taken with a calibrated conductivity cell and meter and completed within 3 to 4 hours of shaking. Care was taken not to disturb the settled soil.

3.3.3. Method 4A1: pH of 1:5 soil/water suspension

This method determines the pH based on a soil/water ratio of 1:5 at 25 ºC (Rayment and Lyons 2011).

A 1:5 soil/water suspension was prepared as described for Method 3A1 for determining EC. Subsequently, all measurements were made within 4 h of conclusion of settling time using a pH and temperature combined electrode.

3.3.4. Method 15D3: Exchangeable bases – 1M ammonium acetate at pH 7.0, rapid method with no pre-treatment for soluble salts

10 g of air-dried, screened (< 2 mm) soil was placed into a 250mL extracting bottle and 100 mL of 1M NH4OAc at pH 7.0 was added. The bottle was gently shaken end-over-end for approximately 30 min at 25 ºC.

Within 30 min of completion of shaking, a portion of the extract was transferred into clean, dry tubes and centrifuged to obtain a clear supernatant. Any floating organic matter was removed from individual tubes following centrifugation during the filtration process.

Exchangeable Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} were determined using Inductively Coupled Plasma – Atomic Emission Spectrometry (ICP-AES).

3.3.5. US EPA Method 3051 – Microwave assisted digestion of sediments, sludges, soils and oils

This method provides a rapid, multi-element acid leach digestion prior to analysis with an ICP-AES (USEPA 2007).

Samples, up to 0.5g, were digested in 10 mL of concentrated nitric acid for 10 min and heated to 175 ºC approximately 5.5 min into the process. The sample was then allowed to settle, centrifuged and filtered before analysis using an ICP-AES.

3.3.6. Black (1965): Soil moisture content

Subsamples of each soil were taken to determine the gravimetric air-dry and oven-dry moisture content of the soils prior to core preparation. The method used was consistent with Black (1965) and involved drying 1 to 100g soil samples in an oven between 100ºC and 110 ºC. Samples were allowed to remain in the oven for three days (72 h) with their lids removed. After three days, the samples were immediately weighed accurate to ±0.001g. The moisture content was calculated using (Equation 3.1):

$$\theta_{dw} = \left(\frac{W_{wet\ soil}}{W_{dry\ soil}} - 1\right) x\ 100 \qquad \text{Eq 3.1}$$

3.4. Preparation of soil cores

Stormwater pipe (75 mm long, 87.5 mm internal diameter), with 1 mm aperture fibreglass gauze tightly attached to one end, was filled to level with soil and weighed to determine the mass of soil contained. The core was then dropped three times from a height of 50 mm three times and the settlement was measured. The bulk density was calculated from the settled soil. This process was repeated three times for each soil type and averaged to obtain the bulk density used to repack each soil core.

A Whatman No.4 filter paper was placed in the bottom of each core. The soil was packed to a height of 50 mm at the required bulk density. This density was achieved by accurately weighing and compacting the soil in two 25 mm layers to ensure even compaction over the 50 mm height of the core. This was then covered with a further 2 filter papers to avoid surface disturbance from the $CaCl_2$ solution applied during experimentation.

20 cores were made for each soil; with 4 replicates of 5 different EC values of the $CaCl_2$ solution.

3.5. $CaCl_2$ solution details

Calcium Chloride ($CaCl_2$) was chosen as the percolating solution due to its use as the pre-treatment solution in TEC analysis used by the NCEA (Bennett and Raine 2012). The use of calcium chloride ensured the soil doesn’t disperse and seal, reducing the hydraulic conductivity.Ca is a divalent ion that shows greater affinity to soil CEC sites than Na, Mg and K. The use of a homogenous ionic concentration with greater affinity to soil CEC than cations known to be contained on soil exchange sites provides for the greatest chance to analyse exchange phenomena.

The solution was prepared by accurately weighing the mass of $CaCl_2$, listed in Table 3.3, for the desired concentration and diluting this with 20 L of water.

Table 3.3 Details of $CaCl_2$ solution

EC (dS/m)	*$CaCl_2$ (g) per 20 L H_2O*	*$mg.L^{-1}$ (Ca^{2+})*	*mg per PV*
0.5	7.36	132.9	19.935
1	14.72	265.8	39.87
2	29.44	531.6	79.74
4	58.88	1063.2	159.48
8	117.76	2126.4	318.96

3.6. Leaching and leachate collection

The prepared soil cores were placed into Buchner funnels held in place by a rack for leaching. A constant hydraulic head of between 1 cm and 5.7cm (depending on soil swelling extent) was achieved by supporting inverted 1250 cm^3 bottles containing the respective $CaCl_2$ solutions (EC 0.5, 1, 2, 4, 8 dS/m) above the soil cores. The constant hydraulic head was maintained throughout the entire leaching period. Plastic collection containers marked with the required pore volume were situated beneath the Buchner funnels to capture leachate in pore volumes (Figure 3.2).

Figure 3.4 Photograph of experimental setup.

As each complete PV was collected from the soil, the time to collect it was recorded and the leachate was sealed to avoid the effects of evaporation and contamination of the samples prior to weighing, EC measurement and dilution for testing with an Atomic Absorption Spectrophotometer (AAS).

3.7. Soil leachate chemical analysis

3.7.1. EC

Samples were tested for EC as a means of potentially determining if the soil core has reached chemical equilibrium. EC was determined directly from leachate using a TPS MC-84 EC meter.

3.7.2. Soluble cation concentration determination

Atomic adsorption spectrophotometry (AAS) was used to determine the soluble cation components (Na^+, K^+, Mg^{2+}, Ca^{2+}) of the leachate. The methods used were modified versions of Rayment and Higginson (1992) methods L1b, L2b, L3b and L4b. Modifications include no use of ionising suppressants and no use of a centrifuge or filter (samples were allowed to settle and diluted 1:100 for analysis).

AAS testing was performed using a Shimadzu AA-7000 Atomic Absorption Spectrophotometer with a Shimadzu ASC-7000 Auto Sampler. Samples were diluted down to 1:100 in order to be within the instrument detection range.

3.8. Hydraulic conductivity

Weighing of the leachate and timing of the duration required to obtain leachate enabled HC to be determined, allowing insight into whether or not complete chemical equilibrium is required to reach hydraulic conductivity steady state conditions. Saturated hydraulic conductivity for a vertical soil core under constant head is found by Equation 3.2 (Hillel 2004):

$$K_{sat} = \frac{VL}{AHt} \qquad \text{Eq 3.2}$$

Where V is the volume of solution (cm^3), L is the length of the soil core (cm), A is the area of the soil core (cm^2), H is the water head from base of core to top of solution (cm) and t is the time for V to flow through (h). The units for K_{sat} are cm/h.

The average mass of the container that the Brown Tenosol samples were collected in is 44.571 g. An average mass of water per PV of 140g was assumed for the Black Vertosol and Red Ferosol as no readings were taken of these.

3.9. Statistical Analysis

Statistical analysis to determine significant differences between results was undertaken using Minitab V14 Student Edition. This was accomplished by performing a one-way ANOVA with a confidence interval of 95%. Where significant differences were detected, pairwise differences were determined by performing a Tukey's Honest Significant Difference (HSD) analysis.

3.9.1. One-way ANOVA

A one-way ANOVA analysis was performed using two different comparisons: between treatment and within treatment.

Between treatment analysis was performed for the cation exchange curves presented in the results section. This is in order to determine if there is a significant difference between the concentrations of cations being removed between different treatments (in this project, different strength solutions).

Within treatment analysis was undertaken with all data presented to determine if there were significant differences between the total concentrations removed, electrical conductivity or hydraulic conductivity at different PV's.

3.9.1.1. Skew corrections

Some data sets contained a certain degree of skew and were treated in the following manner to allow analysis, as suggested by Tabachnick and Fidell (2007) (Equations 3.3 to 3.7).

Moderately Positive

$$X_{new} = \sqrt{X} \tag{Eq 3.3}$$

Substantially Positive

$$X_{new} = \log_{10} X \tag{Eq 3.4}$$

Substantially Positive (with zero values)

$$X_{new} = \log_{10}(X + C) \tag{Eq 3.5}$$

Where C is a constant added to each score so that the smallest score is one (Tabachnick and Fidell 2007).

Moderately Negative

$$X_{new} = \sqrt{K - X} \qquad \text{Eq 3.6}$$

Where K is a constant from which each score is subtracted so that the smallest score is one (usually equal to the largest score plus one) (Tabachnick and Fidell 2007).

Substantially Negative

$$X_{new} = \log_{10}(K - X) \qquad \text{Eq 3.7}$$

3.9.2. Tukey's Honest Significant Difference (HSD)

Tukey's Honest Significant Difference (HSD) test is a method used in conjunction with an ANOVA to determine if means are significantly different from each other. The formula used to calculate Tukey's HSD is (Equation 3.8):

$$HSD = \pm q(\alpha, v, a) * \sqrt{\frac{MSE}{n}} \qquad \text{Eq 3.8}$$

Where q is a function of α, v and a and is determined from the Studentized Range Distribution, α is the confidence level the ANOVA was taken at, v is the degrees of freedom of the residual error, a is the number of means, MSE is the mean square error of the residual and n is the number of replicates.

4. Results

This section details the results of this project and highlights the major observations. For the three soils (Black Vertosol, Red Ferosol and Brown Tenosol) results for leachate sodium concentration (Na), magnesium concentration (Mg), potassium concentration (K), electrical conductivity (EC) and saturated hydraulic conductivity (HC) are presented.

Statistical analysis was undertaken for leachate cation concentration (Na, Mg and K), however it was not utilised for EC and HC. For EC, the graphs presented in this section show a flat line over the duration of the experiments, while for HC, the data was too erratic to allow significant statistical analysis to take place.

4.1. Black Vertosol

Leachate from the Black Vertosol was collected for 10 PV's.

AAS data can be found in Appendix B, Sections 1 to 5.
EC data can be found in Appendix H.
HC data can be found in Appendix E.
Statistical data can be found in Appendix K, Section 1.

4.1.1. Sodium

Sodium was observed to have been leached in majority from soil solution and colloidal exchange sites for EC 2, 4 and 8 dS/m solutions after 10 PV (Figure 4.1).

Both EC 8 dS/m and EC 4 dS/m solutions had reached this point at approximately PV 6 and the EC 2 dS/m treatment at PV 8.

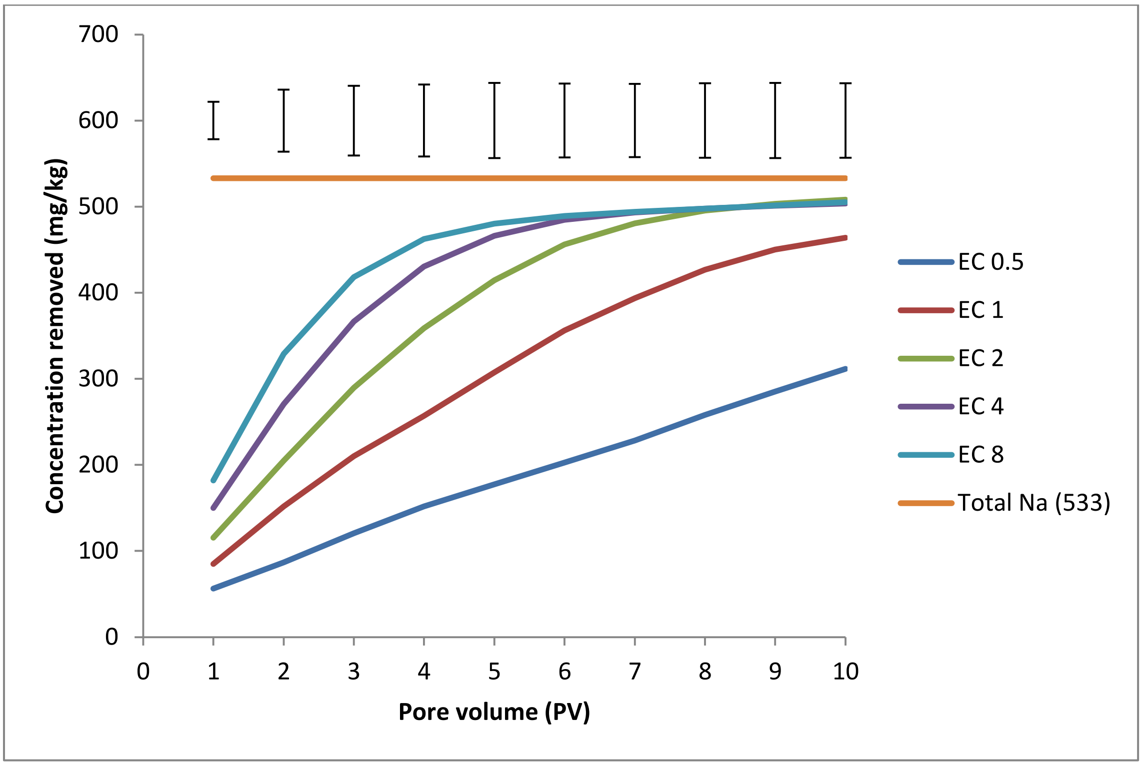

Figure 4.1 Cumulative concentration of sodium removed from Black Vertosol soil cores. Bars located at the top of the graph are Tukey's HSD bars (α = 0.05) for between treatment ANOVA. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±27.49), EC 1 dS/m (±24.01), EC 2 dS/m (±26.6), EC 4 dS/m (±52.12), EC 8 dS/m (±36.17).

EC 0.5 and EC 1 dS/m solutions were not observed to reached this point at PV 10. By extrapolating the cation exchange curves for EC 0.5 and EC 1 dS/m solutions in a linear fashion, total Na exchange and leaching (503 mg/kg) occurs at PV 13 and at PV 17, respectively.

4.1.2. Magnesium

After 10 PV, it was observed that only 18.6% of the total Mg contained in the soil (5767 mg/kg) was leached by the EC 8 dS/m solution. All other EC solutions leached progressively less Mg as the electrolyte concentration of the percolating solution was reduced (Figure 4.2). Of particular note, the EC 0.5 dS/m solution leached two orders of magnitude less Mg than the EC 8 dS/m solution.

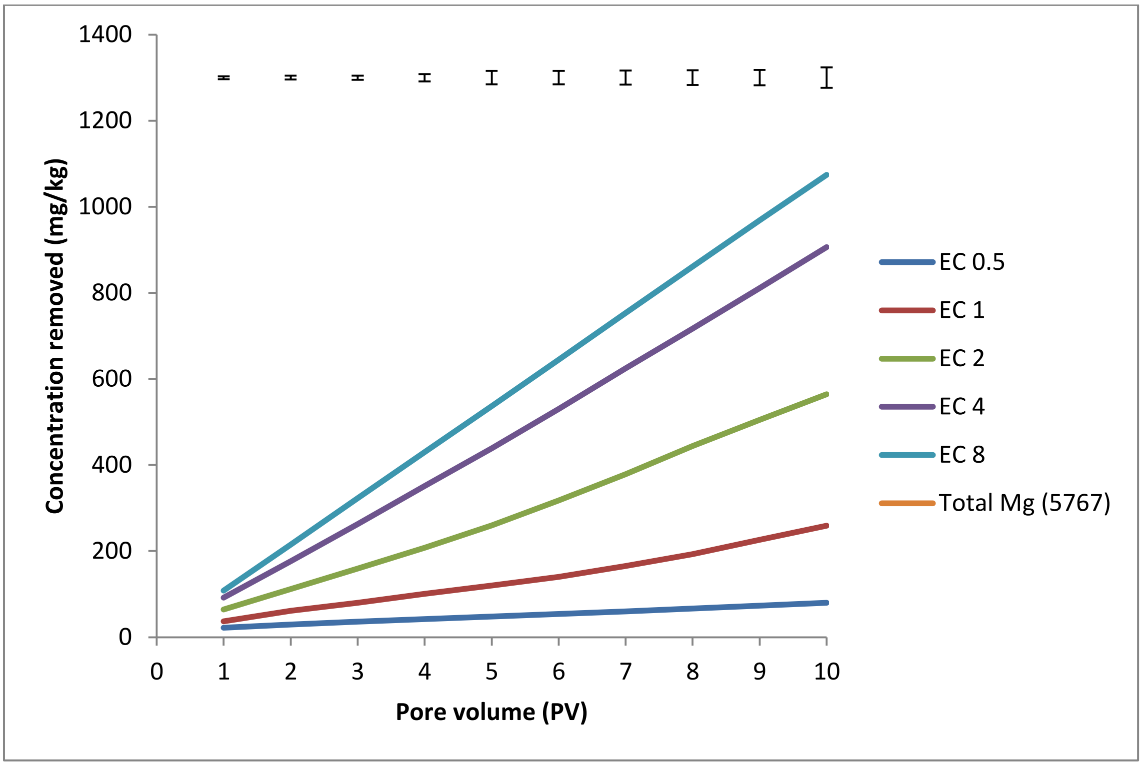

Figure 4.2 Cumulative concentration of magnesium removed from Black Vertosol soil cores. Bars located at the top of the graph are Tukey's HSD bars (α = 0.05) for between treatment ANOVA. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±7.41), EC 1 dS/m (±14.06), EC 2 dS/m (±18.26), EC 4 dS/m (±11.71), EC 8 dS/m (±9.43).

The ion exchange curves for all EC solutions appear to follow a linear trend. While it is unlikely that a linear trend would continue to the point of complete removal of MG, without knowing the point at which an asymptote is approached, the use of linear extrapolation to predict total Mg removal from the soil is justified (Table 4.1). From these predictions, even at the strongest EC (8 dS/m), it will take 54 PV's of percolating solution to leach all the Mg from the soil, while for the lowest EC (0.5 dS/m) 889 PV would be required to leach all Mg.

Table 4.1 Predictions of PV when all Mg will be removed from Black Vertosol.

Solution EC (dS/m)	*Concentration removed (mg/kg/PV)*	*PV prediction*
0.5	6.5	889
1	24.6	234
2	55.6	104
4	90.5	64
8	107.4	54

4.1.3. Potassium

At the strongest EC (8 dS/m), only 7.1% of the total K contained in the soil (1900 mg/kg) was removed after leaching with 10 PV's (Figure 4.3). In this case, EC 0.5 dS/m leached K was one order of magnitude less than the EC 8 dS/m solution.

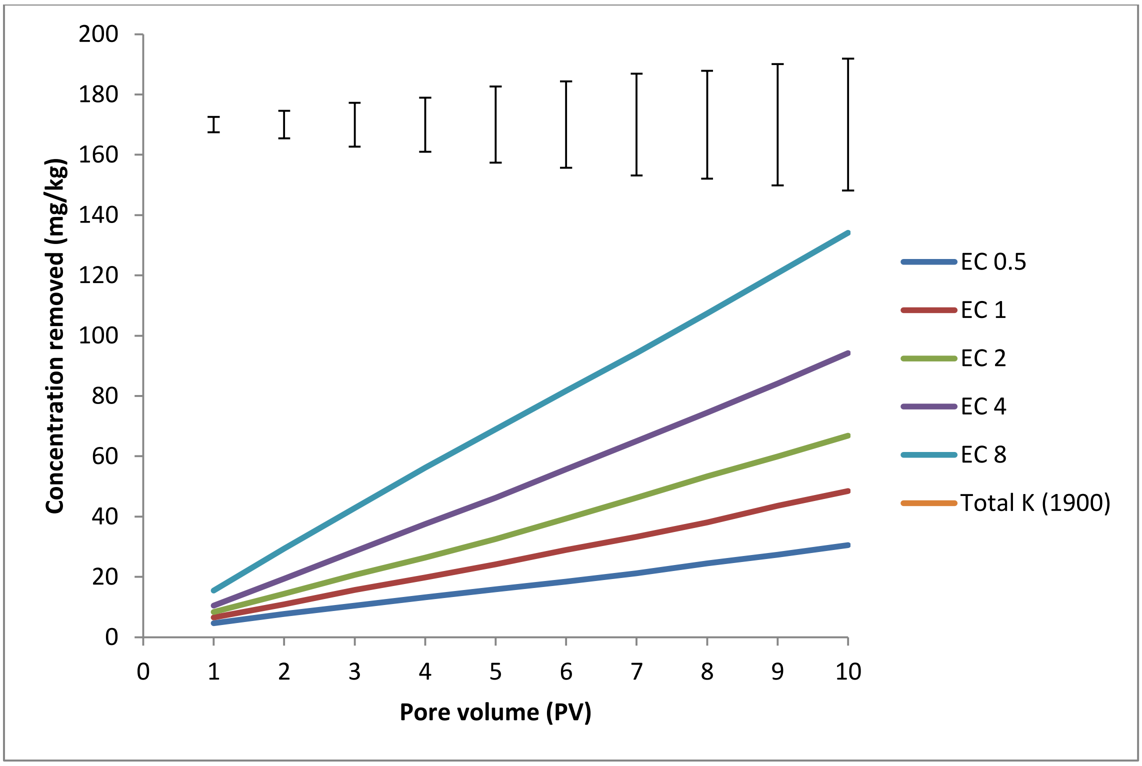

Figure 4.3 Cumulative concentration of potassium removed from Black Vertosol. Bars located at the top of the graph are Tukey's HSD bars (α = 0.05) for between treatment ANOVA. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±9.01), EC 1 dS/m (±8.29), EC 2 dS/m (±7.75), EC 4 dS/m (±19.24), EC 8 dS/m (±12.83).

Again, without knowing the point at which the concentration removed approaches an asymptote, or the curvature of the line approaching this point, a linear extrapolation is justified to predict total K leaching (Table 4.2). Depending on solution electrolytic strength total K leaching was predicted to occur after leaching with 144–659 PV's of $CaCl_2$ percolating solution.

Table 4.2 Predictions of PV when all K will be removed from Black Vertosol.

Solution EC (dS/m)	*Concentration removed (mg/kg/PV)*	*PV prediction*
0.5	2.9	659
1	4.7	408
2	6.5	293
4	9.3	204
8	13.2	144

4.1.4. Electrical Conductivity

From Figure 4.4, it can be noticed that there is a slightly elevated reading for the first PV, as would be expected in removing the soil inherent solute load. After this, the EC reaches a steady state.

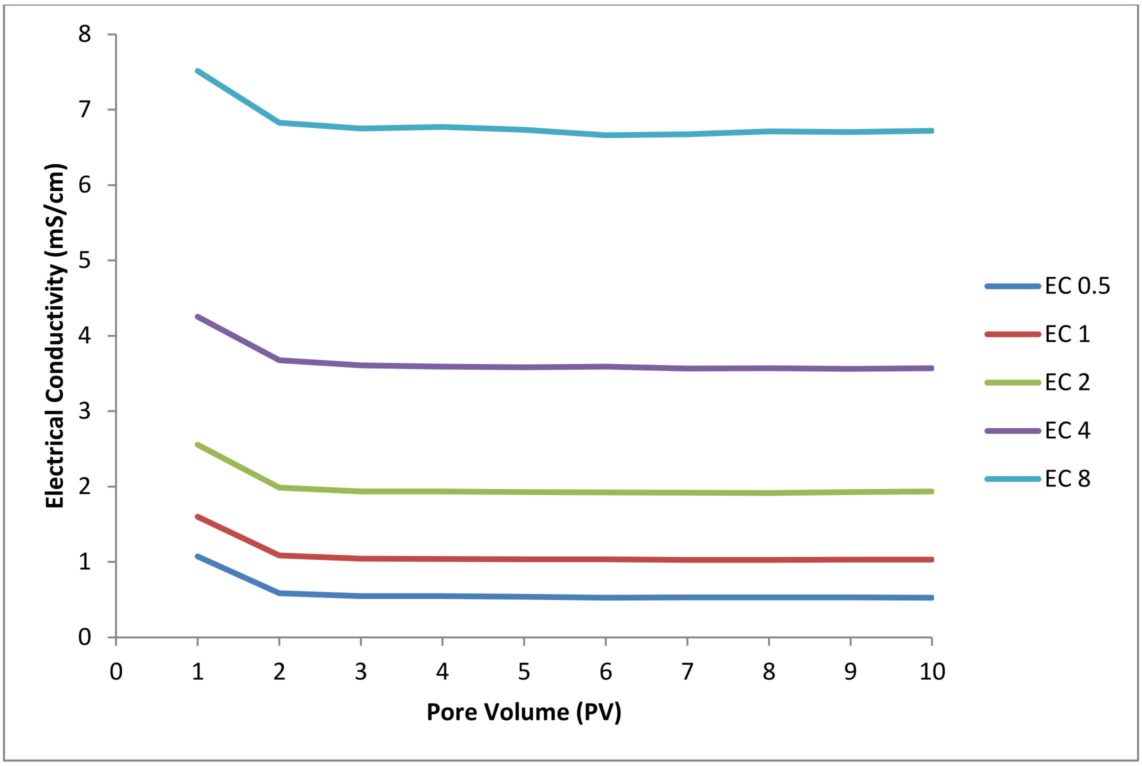

Figure 4.4 EC of leachate from Black Vertosol. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±0.031), EC 1 dS/m (±0.022), EC 2 dS/m (±0.029), EC 4 dS/m (±0.069), EC 8 dS/m (±0.184).

4.1.5. Hydraulic Conductivity

From Figure 4.5, it can be noted that the treatment with the strongest solution (EC 8 dS/m) resulted in the highest HC while the weakest solution (EC 0.5 dS/m) produced the lowest HC. The HC of the other three treatments (EC 1, 2 and 4 dS/m) were between the strongest and weakest treatments, however there was not a trend of increasing HC as the EC of the treatment solution increased.

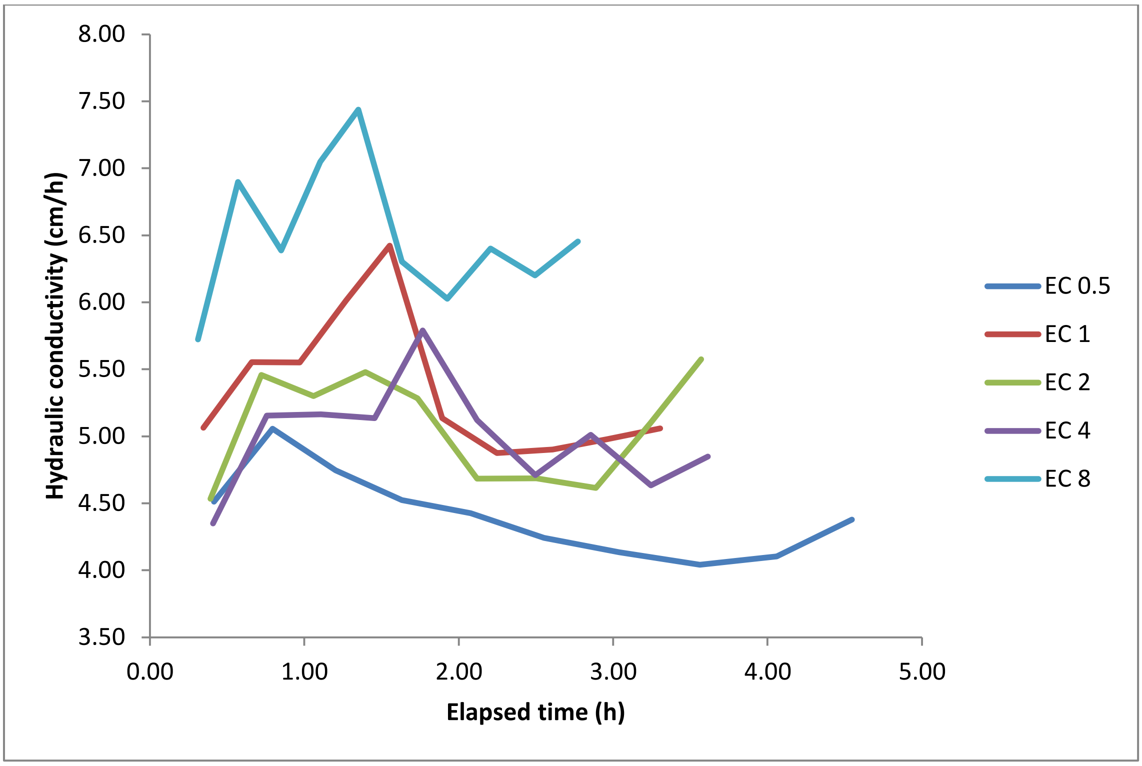

Figure 4.5 HC of Black Vertosol. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±3.64), EC 1 dS/m (±4.17), EC 2 dS/m (±2.62), EC 4 dS/m (±1.65), EC 8 dS/m (±3.12).

Fitting of linear trend lines to the data in Figure 4.5, produces gradients (Table 4.3) that show there is a trend for decreasing hydraulic conductivity over time with the exception being the cores treated with solution with an EC of 2 dS/m which exhibits a very slight upward trend.

Table 4.3 Linear trend line gradients for HC of Black Vertosol.

Solution EC (dS/m)	*Linear trend line gradient (cm/h/h)*
0.5	-0.165
1	-0.2314
2	0.0028
4	-0.0372
8	-0.0616

4.2. Red Ferosol

The Red Ferosol was treated with 10 PV’s of $CaCl_2$ solution also.

AAS data can be found in Appendix C, Sections 1 to 5.

EC data can be found in Appendix I.

HC data can be found in Appendix F.

Statistical data can be found in Appendix K, Section 2.

4.2.1. Sodium

After being flushed with 10 PV’s of $CaCl_2$ solution with EC’s of 4 and 8 dS/m, only 18% of the total Na (300 mg/kg) contained in the soil core has been removed. The curved nature of the sodium exchange curve in Figure 4.6 suggests that total removal of Na may not be possible. This curvature makes it difficult to predict the point at which all Na is removed or an asymptote is reached.

The nature of the lines suggest that it is a decaying function of the PV’s, however fitting lines to suit this data is beyond the scope of this project. However, if a linear trend from PV 10 is assumed, then a linear extrapolation can be used to predict total replacement of Na. As the concentrations are small and the gradients are similar, an average of the concentration removed in PV 10 will be used to predict total replacement, occurring at between 99 and 108 PV’s (Table 4.4).

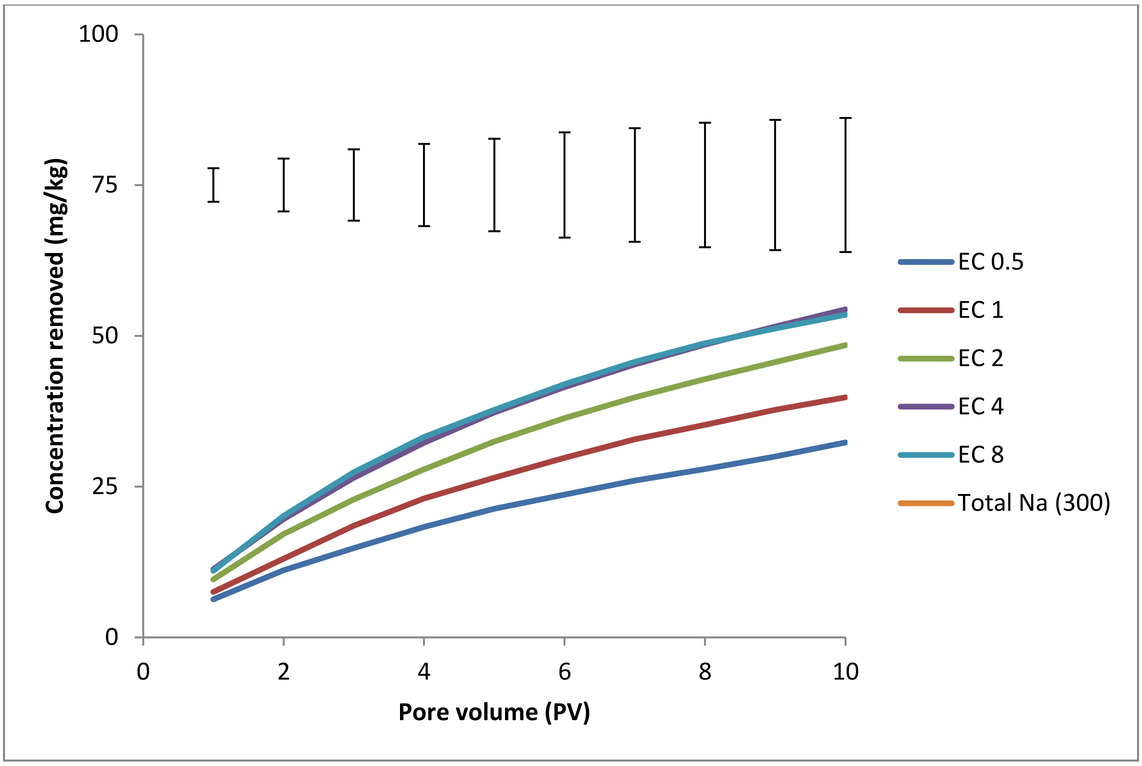

Figure 4.6 Cumulative concentration of sodium removed from Red Ferosol. Bars located at the top of the graph are Tukey's HSD bars (α = 0.05) for between treatment ANOVA. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±6.33), EC 1 dS/m (±3.47), EC 2 dS/m (±11.19), EC 4 dS/m (±5.42), EC 8 dS/m (±9.46).

Table 4.4 Predictions of PV when all Na will be removed from Red Ferosol.

Solution EC (dS/m)	*Concentration removed (mg/kg/PV)*	*PV prediction*
0.5	2.48	108
1	2.48	105
2	2.48	101
4	2.48	99
8	2.48	100

4.2.2. Magnesium

The strongest leaching solution (8 dS/m) has only removed 15.4% of the total Mg contained in the soil after being treated by 10 PV's of solution (Figure 4.7). The strongest solution (EC 8 dS/m) removed one order of magnitude more Mg than the weakest solution (EC 0.5 dS/m). Percolating solutions removed progressively less Mg as the solution concentration decreased.

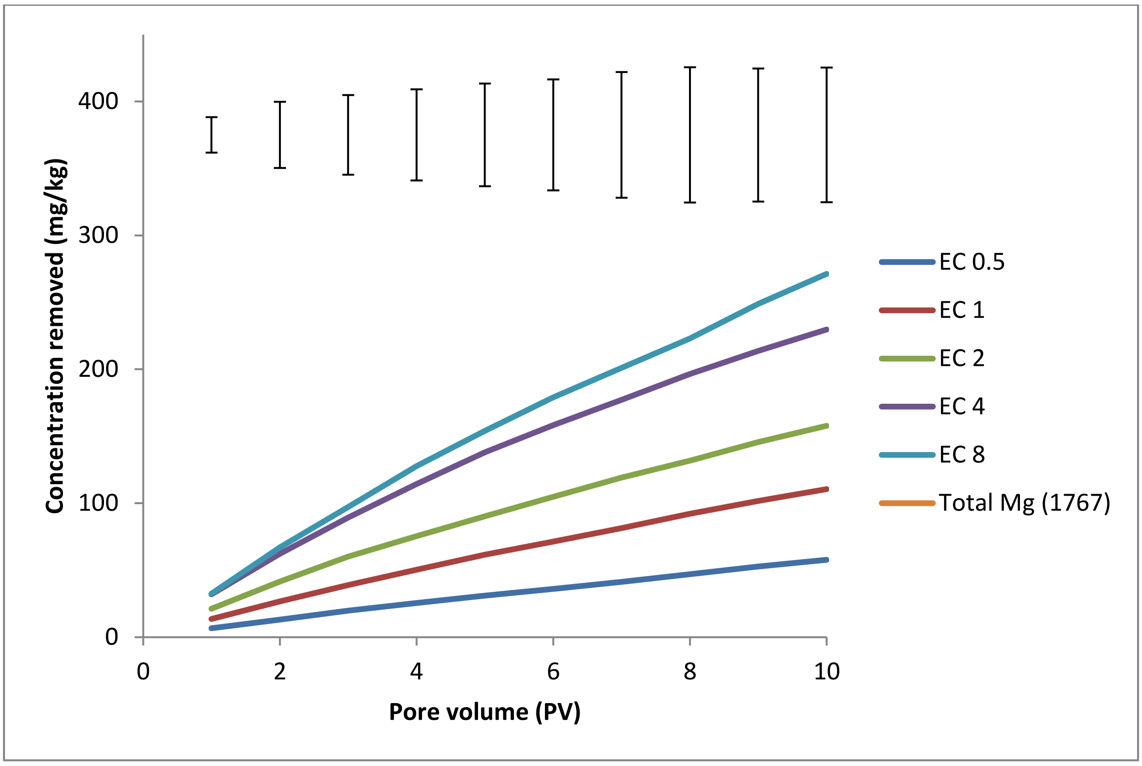

Figure 4.7 Cumulative concentration of magnesium removed from Red Ferosol. Bars located at the top of the graph are Tukey's HSD bars (α = 0.05) for between treatment ANOVA. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±1.79), EC 1 dS/m (±2.92), EC 2 dS/m (±5.10), EC 4 dS/m (±4.19), EC 8 dS/m (±8.21).

Again, there is a very slight curvature to the lines, however for the purposes of further analysis in this project, they will be assumed to be linear and linear extrapolation will be utilised to predict an approximate PV when all Mg will be removed from the soil. . From the predictions in Table 4.5, it can be seen that it will take between 67 and 312 PV's to completely replace all Mg contained in the soil depending on the percolating solution ionic concentration.

Table 4.5 Predictions of PV when all Mg will be removed from Red Ferosol.

Solution EC (dS/m)	*Concentration removed per (mg/kg/PV)*	*PV prediction*
0.5	5.68	312
1	10.8	164
2	15.2	117
4	22.0	81
8	26.5	67

4.2.3. Potassium

Again, the strongest leaching solutions (EC 4 and 8 dS/m) have not completely replaced all K (767 mg/kg) contained in the soil, removing approximately 6.1% of the total K contained in the soil by the time 10 PV's of $CaCl_2$ solution have percolated (Figure 4.8). Interestingly, EC 4 and 8 dS/m, follow a highly similar leaching function over the 10 PV's examined in this study.

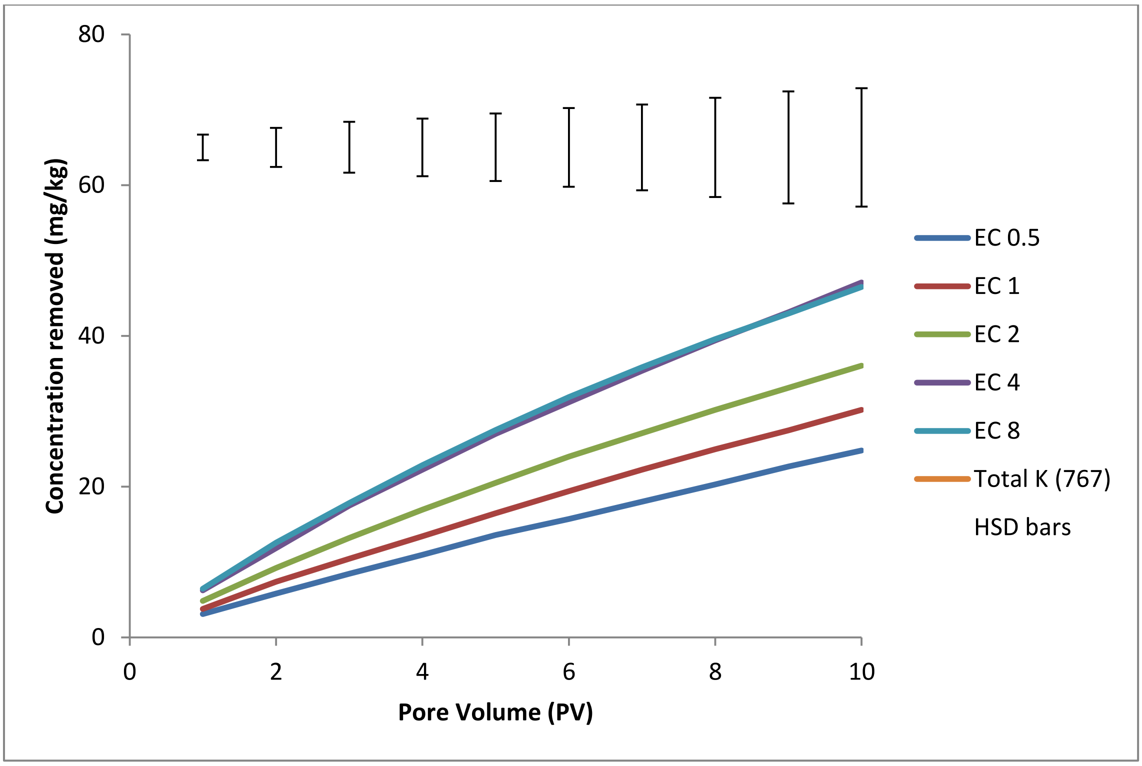

Figure 4.8 Cumulative concentration of potassium removed from Red Ferosol. Bars located at the top of the graph are Tukey's HSD bars (α = 0.05) for between treatment ANOVA. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±6.82), EC 1 dS/m (±3.47), EC 2 dS/m (±11.19), EC 4 dS/m (±5.42), EC 8 dS/m (±9.46).

Again, there is a slight curvature of the data lines, suggesting a decay function. As for Mg, the relationship is assumed to be linear and extrapolation of the leaching function showed that the strongest solutions (EC's of 8 and 4 dS/m) will require approximately 170 PV's and the weakest solution (EC 0.5 dS/m) will require 318 PV's of treatment to leach all K from the soil (Table 4.6).

Table 4.6 Predictions of PV when all K will be removed from Red Ferosol.

Solution EC (dS/m)	*Concentration removed per (mg/kg/PV)*	*PV prediction*
0.5	2.41	318
1	2.93	262
2	3.47	221
4	4.54	169
8	4.45	173

4.2.4. Electrical Conductivity

Very few observations can be made from this graph (Figure 4.9), as the EC readings throughout the 10 PV's appear to be in a steady state condition.

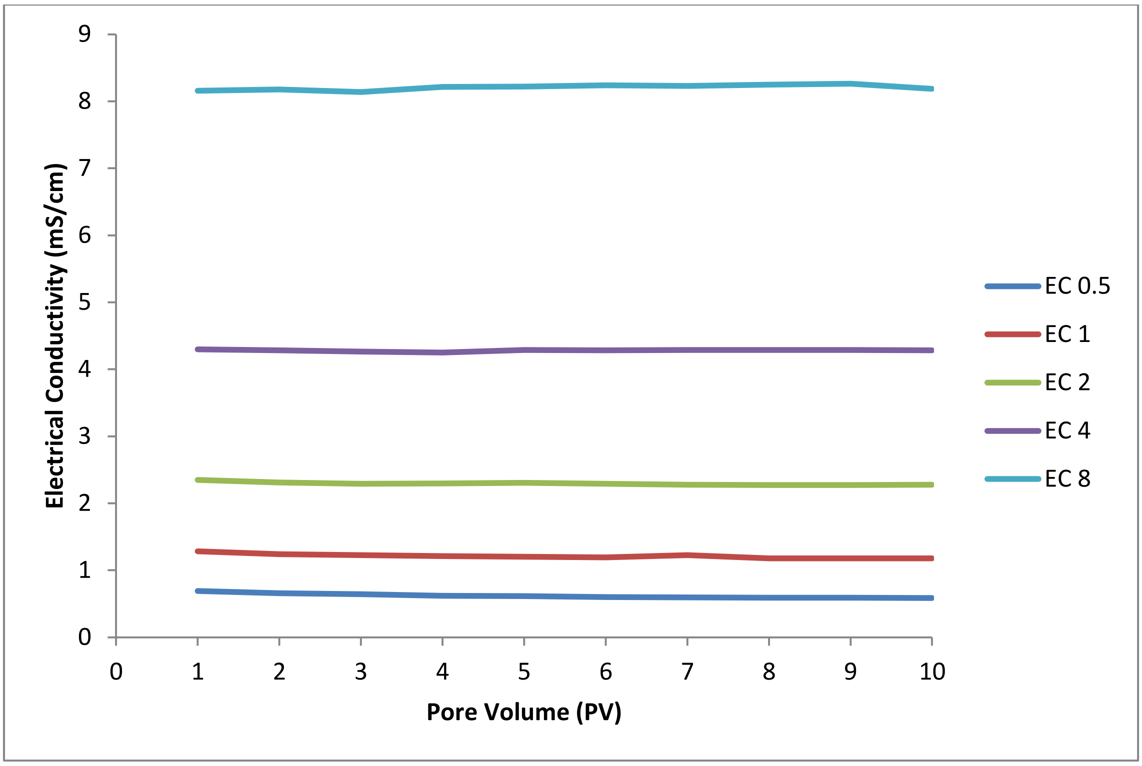

Figure 4.9 EC of leachate from Red Ferosol. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±0.112), EC 1 dS/m (±0.184), EC 2 dS/m (±0.037), EC 4 dS/m (±0.095), EC 8 dS/m (±0.106).

4.2.5. Hydraulic Conductivity

As with the HC graphs for the Black Vertosol, there is a general trend of increasing HC as the EC of the leaching solution increases (Figure 4.10). The exception to this is EC 1 dS/m which is located between EC 4 and 8 dS/m.

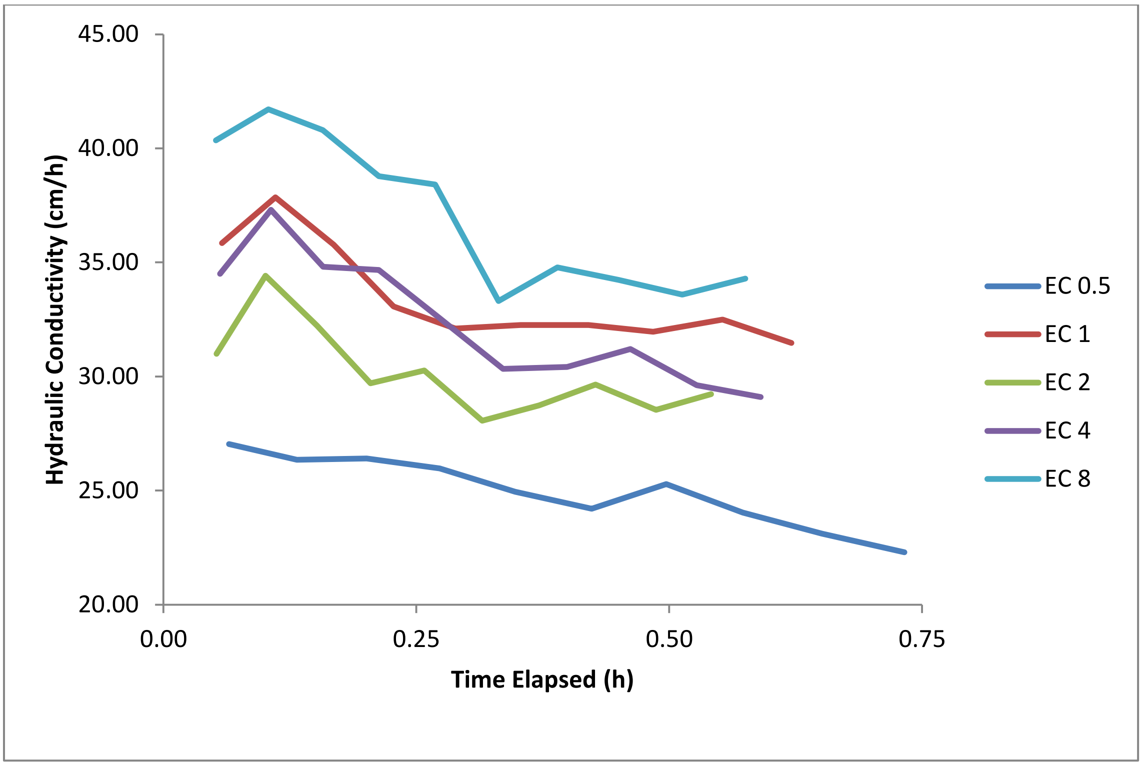

Figure 4.10 HC of Red Ferosol. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±16.5), EC 1 dS/m (±7.63), EC 2 dS/m (±7.36), EC 4dS/m (±14.12), EC 8 dS/m (±13.48).

Fitting of linear trend lines to the data in Figure 4.10, produces gradients (Table 4.7) that show there is a trend for decreasing HC over time.

Table 4.7 Linear trend line gradients for HC of Red Ferosol.

Solution EC (dS/m)	*Linear trend line gradient (cm/h/h)*
0.5	-6.5408
1	-9.3283
2	-8.2618
4	-13.677
8	-16.697

4.3. Brown Tenosol

Due to the behaviour represented by the Black Vertosol and Red Ferosol, the Brown Tenosol was treated with 30 PV's of $CaCl_2$ solution in order to find the point at which the soil will reach chemical equilibrium with the percolating solution.

AAS data can be found in Appendix C, Sections 1 to 5.

EC data can be found in Appendix J.

HC data can be found in Appendix G.

Statistical data can be found in Appendix K, Section 3.

4.3.1. Sodium

The cation exchange curves for Na removal from the Brown Tenosol are shown in Figure 4.11. It can be seen that for both EC's 4 and 8 dS/m, the total concentration removed from the soil actually surpassed the total Na (47 mg/kg) that is in the soil. This is due to errors in the readings from the Atomic Absorption Spectrophotometer (AAS). When concentrations in the sample are extremely low, the 'zero' of the machine tends to wander, resulting in higher readings than what are actually contained in the samples.

As a result of this, statistical analysis was not undertaken. The results, while spurious, do provide some indication that Na might be expected to leach in majority from the soil within 30 PV.

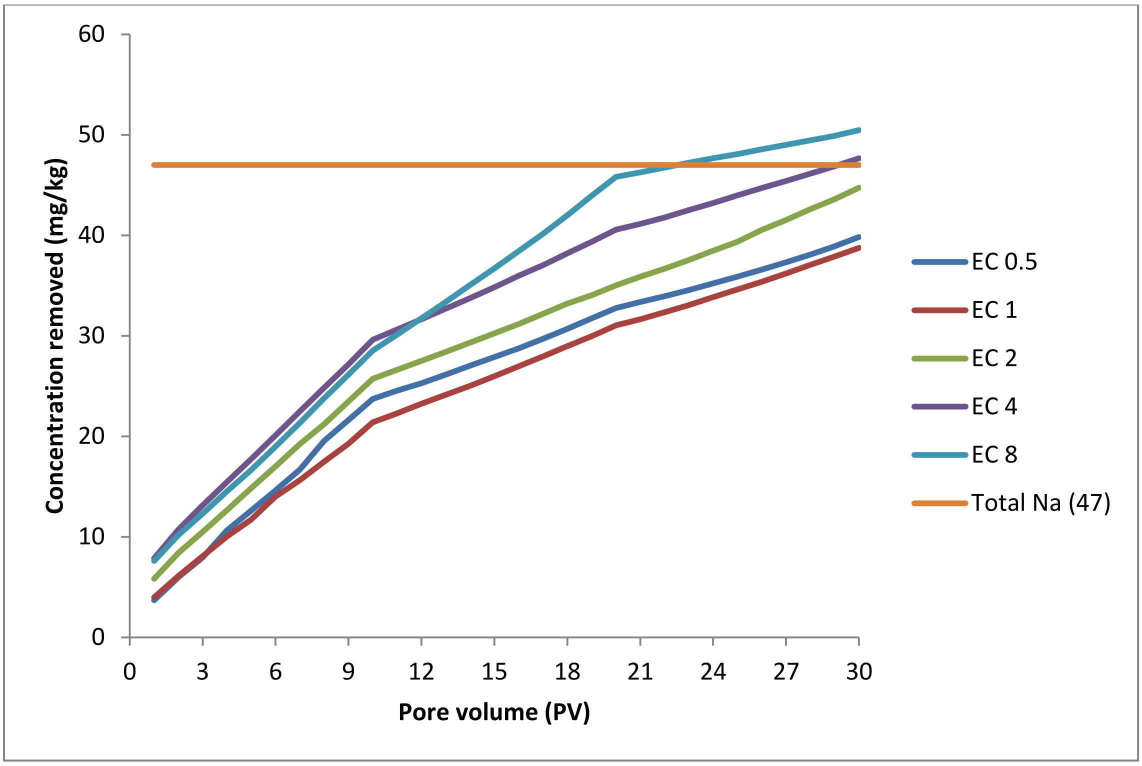

Figure 4.11 Cumulative concentration of sodium removed from Brown Tenosol.

4.3.2. Magnesium

55.4% of the total Mg has been removed by the strongest leaching solution (8 dS/m) by PV 30, compared to 36.4% by the weakest solution (0.5 dS/m). The behaviour of the cation exchange curves for Mg replacement in the Brown Tenosol display some interesting behaviour in that all lines approach parallel eventually (Figure 4.12). Another observation that can be made in the relationship between leaching functions for EC 2 dS/m and EC 4 dS/m. At approximately PV 10, they converge and follow essentially the same linear trend from the point of convergence.

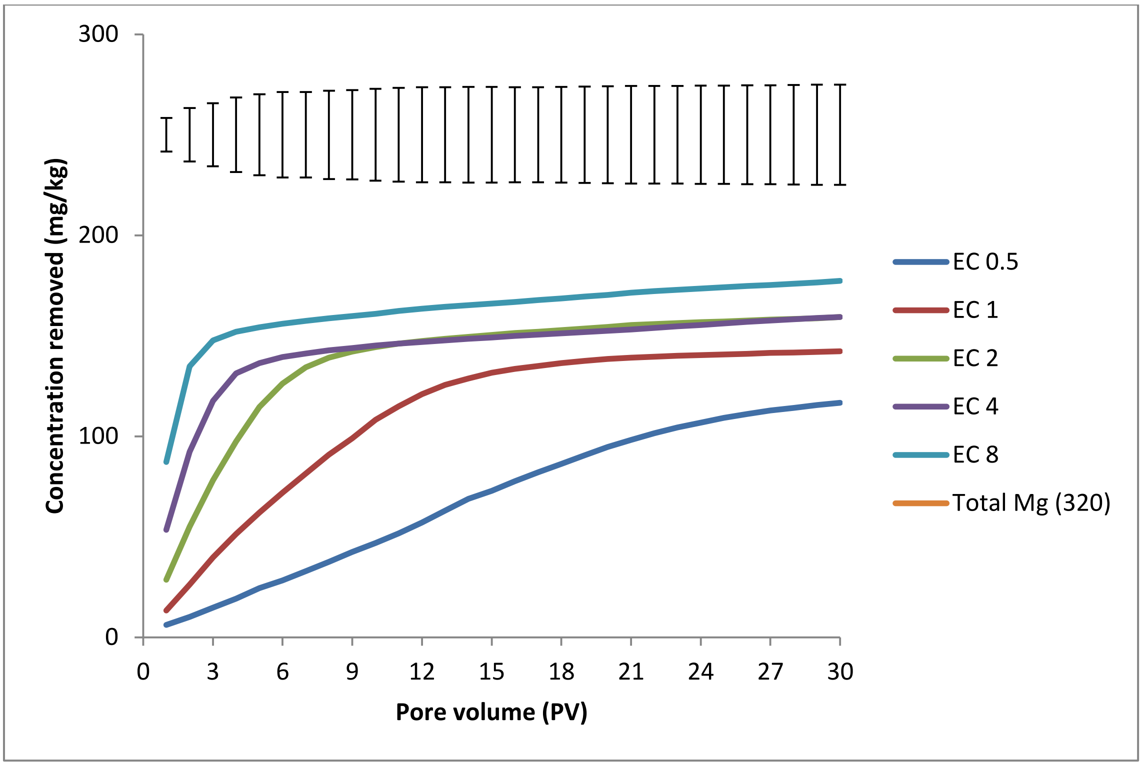

Figure 4.12 Cumulative concentration of magnesium removed from Brown Tenosol. Bars located at the top of the graph are Tukey's HSD bars (α = 0.05) for between treatment ANOVA. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±0.73), EC 1 dS/m (±0.58), EC 2 dS/m (±0.79), EC 4 dS/m (±1.56), EC 8 dS/m (±0.45).

If we assume that this linear trend will continue until complete replacement of Mg from the soil has occurred, then we can extrapolate the lines in a linear fashion (Table 4.8).

Table 4.8 Predictions of PV when all Mg will be removed from Brown Tenosol.

Solution EC (dS/m)	*Concentration removed (mg/kg/PV)*	*PV prediction*
0.5	0.76	297
1	0.76	263
2	0.76	241
4	0.76	241
8	0.76	217

4.3.3. Potassium

After 30 PV's of treatment with the strongest solution (8 dS/m), 18.8% of the total K has been removed, compared with 7.1% removed by the weakest solution (0.5 dS/m). As with Mg above, the behaviour of the lines for K approaches parallel (Figure 4.13). This enables linear extrapolation of these lines to potentially predict the point at which all K (912 mg/kg) will be removed from the soil (Table 4.9).

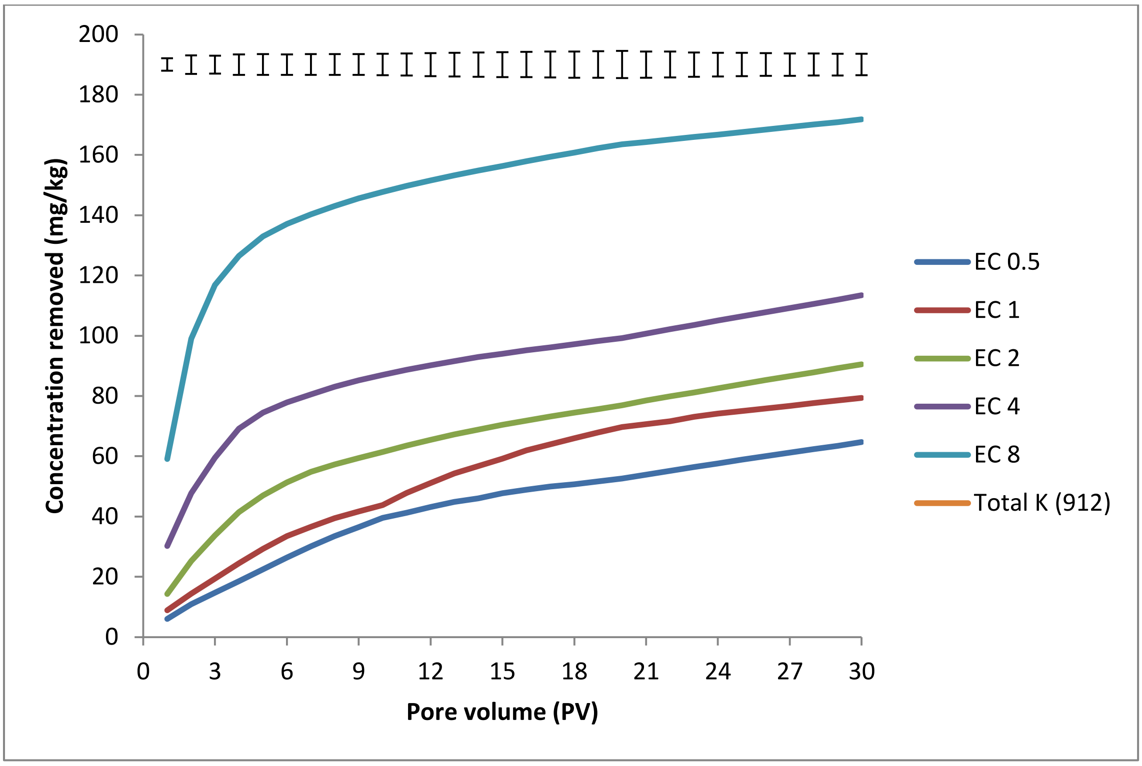

Figure 4.13 Cumulative concentration of potassium removed from Brown Tenosol. Bars located at the top of the graph are Tukey's HSD bars (α = 0.05) for between treatment ANOVA. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±29.9), EC 1 dS/m (±46.11), EC 2 dS/m (±62.63), EC 4 dS/m (±81.9), EC 8 dS/m (±81.9).

Table 4.9 Predictions of PV when all K will be removed from Brown Tenosol.

Solution EC (dS/m)	*Concentration removed (mg/kg/PV)*	*PV prediction*
0.5	1.2	735
1	1.2	723
2	1.2	714
4	1.2	695
8	1.2	647

4.3.4. Electrical Conductivity

As exhibited by the EC curves for the Black Vertosol, there is a slightly elevated reading for the first PV (Figure 4.14), as would be expected in flushing inherent soil solute load. After this the readings once again appear to reach a steady state leachate concentration.

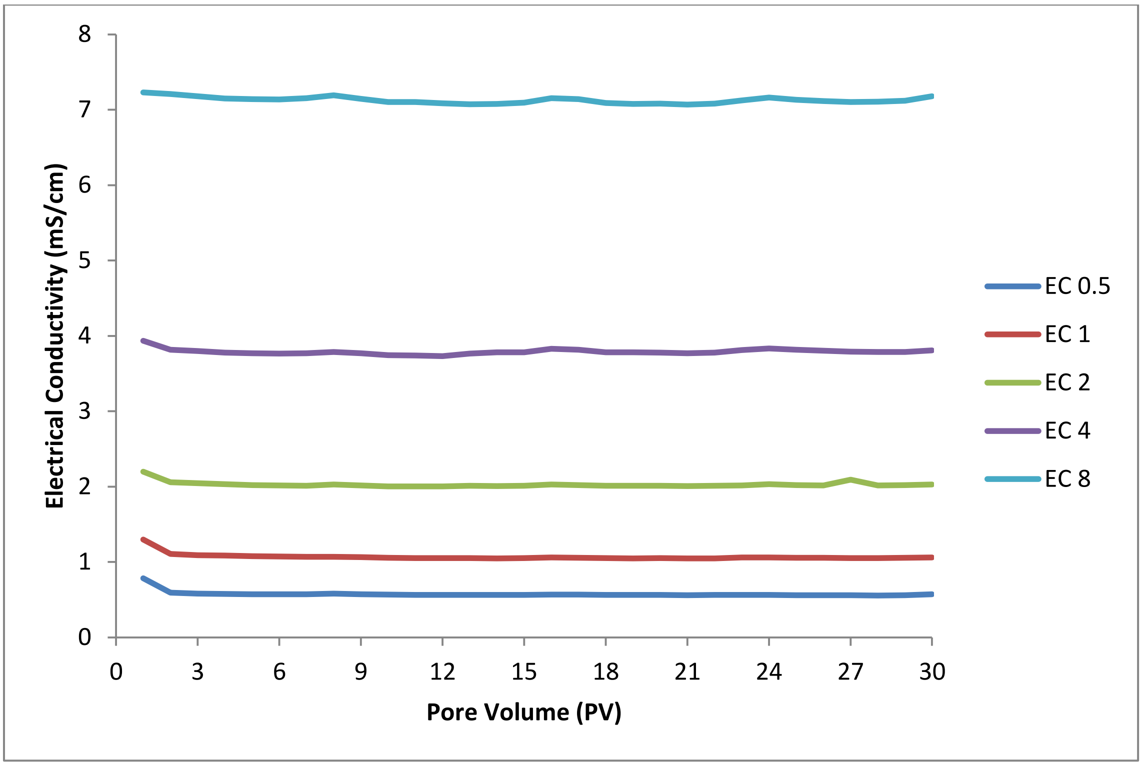

Figure 4.14 EC of leachate from Brown Tenosol. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±0.033), EC 1 dS/m (±0.012), EC 2 dS/m (±0.062), EC 4dS/m (±0.083), EC 8 dS/m (±0.082).

4.3.5. Hydraulic Conductivity

An interesting observation that can be made about the HC data presented in Figure 4.15 is that the HC of EC's 4 and 8 dS/m are lower than EC's 0.5, 1 and 2 dS/m.

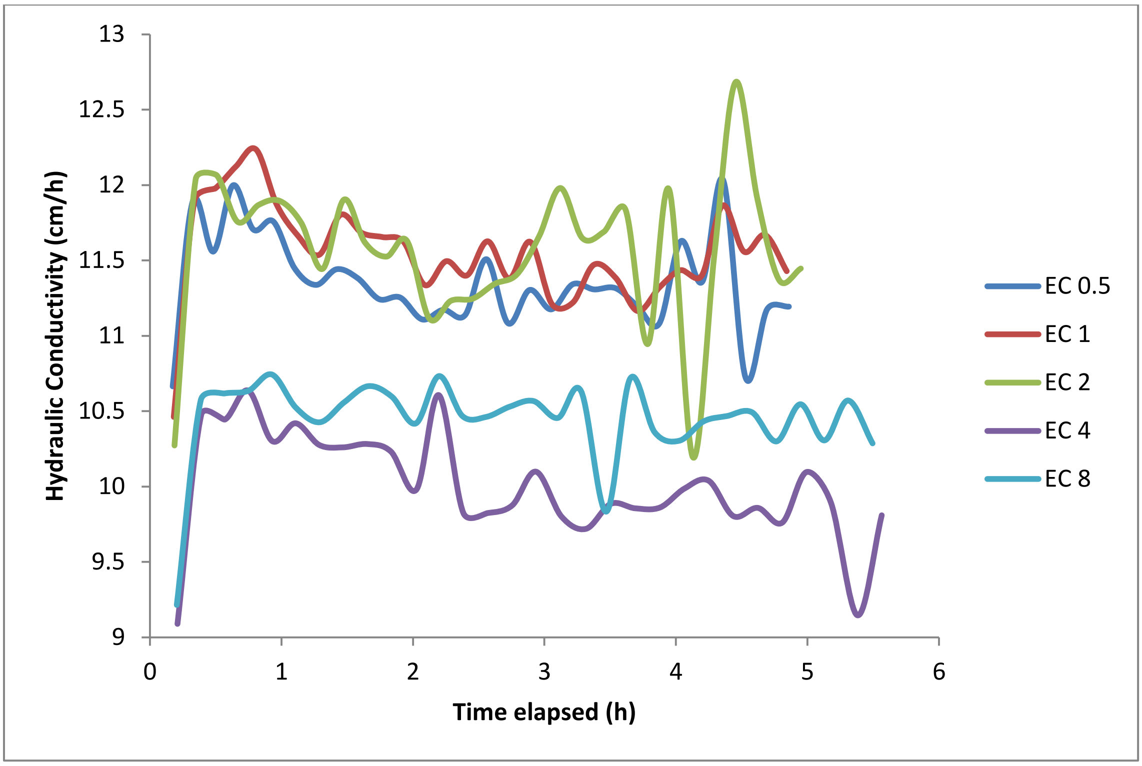

Figure 4.15 HC of Brown Tenosol. Tukey's HSD values (α-0.05) for within treatment analysis: EC 0.5 dS/m (±3.97), EC 1 dS/m (±5.30), EC 2 dS/m (±6.48), EC 4dS/m (±4.69), EC 8 dS/m (±5.51).

Fitting of linear trend lines to the data in Figure 4.15, produces gradients (Table 4.10) that show there is a general trend of decreasing HC over time.

Table 4.10 Linear trend line gradients for HC of Brown Tenosol.

Solution EC (dS/m)	*Linear trend line gradient (cm/h/h)*
0.5	-0.0591
1	-0.0624
2	-0.0037
4	-0.1077
8	-0.0002

5. Discussion

5.1. The effect of percolating solution electrolytic strength on ion exchange

In the majority of cases examined in this study, an increase in solution electrolytic strength has correlated to an increased rate of cation exchange. However this relationship is not linear in that a doubling of solution strength does not necessarily result in doubling the exchange rate, suggesting that both diffusion and mass transfer ion exchange processes are governing the exchange rates.

The case that exhibited the fastest rate of exchange was that of Na replacement in the Black Vertosol, which approached equilibrium (near total replacement) within 10 PV with the 3 strongest solutions (8, 4 and 2 dS/m). For the Red Ferosol, the rate of Na exchange was markedly slower, with predictions of total Na replacement taking between 99 and 108 PV's. Due to machine error for leachate measurements of the Brown Tenosol, it is difficult to know exactly when all Na was replaced but it is likely that the majority has been replaced within the 30 PV's examined, even with the error. While unable to find any specific literature explaining the reasons for the much slower exchange of Na in the Red Ferosol, this may be attributed to oxidisations binding aggregates more strongly and reducing within aggregate permeability, not allowing sufficient access for the percolating solution and favouring preferential flow of macrospores (Bennett 2012), discussed in the next section.

The behaviour of Mg and K cation exchange curves for the Brown Tenosol exhibit two distinct reaction rates; a faster, curved exchange rate initially and a slower, linear rate after a certain number of PV's. Beckett and Nafady (1967) propose that this is due to the specific (Gapon) and non-specific exchange sites. They attribute the curved section to the specific exchange sites located on edges of clay plates (diffusion controlled) and the linear section to the non-specific sites located on planar surfaces (mass-transfer controlled). Another possible explanation of these two different exchange rates is the location of the cations in the soil and the hydraulic pressure head. Under saturated flow, macropores are the dominant pores and present preferential flow paths. Micropores, on the other hand, contribute to a significantly smaller proportion of total hydraulic conductivity (Hillel 2004). Hence, the more rapid leaching of cations could be attributable firstly to the soil solution and then to ion exchange within preferential flow paths. This study suggests, for some soils and ionic species, that a seemingly constant cation concentration is leached, irrespective of solution concentration (i.e. cumulative leaching functions become parallel). Hence, cations that are located within aggregates or micro-pores may take substantially longer to exchange into the percolating solution.

Mg replacement in the Black Vertosol exhibited the best linear relationship, enabling comparisons to be made between solutions of different electrolytic strengths. While a solution with an EC of 8 dS/m is twice as strong as one with an EC of 4 dS/m, it only replaced Mg 18.5% faster. At the opposite end of the spectrum, a solution with an EC of 1 dS/m replaced Mg 222% faster than the EC 0.5 dS/m solution did. This shows that there are factors outside the solution concentration having an impact on the exchange rates.

For the case of K exchange in the Red Ferosol, the exchange curves representing EC 4 and 8 dS/m follow the same path over the 10 PV’s leached in this study. This behaviour suggests that the accessibility of exchange sites, rather than the strength of the percolating solution is having the biggest impact on the exchange rate. This may be due to the inability of the solution to flow through micro-pores as the HC of the soil is high, reducing the time for the solution to find the smaller pores.

5.2. Soil pore volumes required to leach to effect chemical equilibrium

While the numbers of PV’s needed to reach chemical equilibrium presented in the Results section seem high, they are confirmed by the work of Reading *et al.* (2012) who conducted similar work concerned with gypsum Ca availability and exchange within a Vertosol. While the methodology may be slightly different, a comparison of results can be made and the nature of Na removal and PV’s required to fully replace Mg are similar.

From the data obtained in this study, it can be hypothesised that there are many factors affecting the cation exchange curves for soils. Among these could be clay mineralogy and access of percolating solution to exchange sites, whether that be in micro-pores or if ions are locked inside aggregates or oxidisations. The biggest difference, from data accessible for this study, is the difference in clay mineralogy between the three soil types investigated; the Black Vertosol is high in 2:1 clays, the Red Ferosol high in 1:1 clays and the Brown Tenosol a sandy soil.

The 2:1 clays have exchange sites located on the outside of the clay tactoids, on the edges and also within the clay sheets (Odom 1984). The slower exchange rate of K compared to Mg and Na may be attributed to the smaller hydrated radius of a K ion being able to fit in the smaller exchange sites located within the clay sheets, limiting access of the solution (Dolcater *et al.* 1968). Consequently it may take many PV's to eventually make a soil high in 2:1 clays a homoionic system, due to the mass-transfer process that must take place to enable Ca ions to filter their way through the clay structure. While 1:1 clays do not have exchange sites located within the clay components, the Red Ferosol studied has a tendency to form oxidisations that may also limit access by the percolating solution, thus slowing down the reaction rate.

Evidence of oxidisations potentially impacting on cation exchange rates are exhibited by all 3 measured cation replacement curves (Na, Mg and K) in the Red Ferosol. While predictions of attainment of chemical equilibrium have been made using a linear extrapolation, the general shape of these exchange curves suggest a decaying rate of exchange as the number of PV's increase. However, by assuming a linear relationship, Mg will be totally replaced in 31 PV's before Na replacement and 106 PV's before total K exchange.

The effect of macro and micro pores on the accessibility of the percolating solution to the exchange sites cannot be underestimated. Due to their larger size, flow through the macro-pores will be preferred due to the larger energy requirement for the solution to flow through the micro-pores (Beven and Germann 1982). The preferred flow of the solution through the larger pores may likely result in less solution passing through the micro-pores, limiting the exchange rates of the cations contained and exposed in these spaces. The increased exposure time of the top of the soil core may contribute to an increased rate of exchange at the top compared to the bottom and is likely to reach chemical equilibrium faster. With exception to the leaching of Na in the Vertosol, and potentially the Tenosol, the number of PV required to attain chemical equilibrium far exceeds the 10–30 PV in which chemical equilibrium was expected to have occurred (for the Vertosol higher concentration solutions 4 and 8 dS/m) ; Tang and Sparks (1993) showed that exchange kinetics are normally rapid, occurring within milliseconds, with exception to interlayer exchanged K contained in 2:1 clays.

5.2.1. Efficiency of exchange

From the data presented in this study, the following efficiency measures can be estimated based on the charge composition of the $CaCl_2$ solution before leaching and the leachate collected (Tables 5.1, 5.2 and 5.3).

Table 5.1 Efficiency of total cation exchange for Black Vertosol, Red Ferosol and Brown Tenosol.

PV	*EC 0.5 dS/m (%)*	*EC 1 dS/m (%)*	*EC 2 dS/m (%)*	*EC 4 dS/m (%)*	*EC 8 dS/m (%)*
			Black Vertosol		
1	1.01	1.57	2.29	3.08	3.72
5	2.94	5.51	8.62	11.60	13.25
10	5.15	9.40	13.90	18.34	20.90
			Red Ferosol		
1	0.56	0.87	1.26	1.74	1.76
5	2.32	3.68	5.05	7.14	7.73
10	4.05	6.37	8.55	11.69	13.10
			Brown Tenosol		
1	1.25	2.04	3.81	7.16	12.03
5	4.65	8.06	13.78	17.88	23.76
10	8.61	13.56	18.10	20.46	26.36
30	17.29	20.36	23.04	25.06	31.24

The EC 8 dS/m consistently leaches a greater percentage of the total cations across all three soils in this study. If we assume a cation exchange efficiency of 100%, Table 5.4 predicts how long it will take to reach equilibrium for the three soils at the five solution concentrations.

Table 5.2 PV predictions of chemical equilibrium based on 100% exchange efficiency.

Solution EC (dS/m)	*Black Vertosol (PV)*	*Red Ferosol (PV)*	*Brown Tenosol (PV)*
0.5	52.55	17.31	6.02
1	26.27	8.66	3.01
2	13.14	4.33	1.50
4	6.57	2.16	0.75
8	3.28	1.08	0.38

The numbers contained in Table 5.4, assuming 100% exchange efficiency, show that any way to increase the efficiency of ion exchange in soils, whether it be through increased contact time or binding to an agent in the soil that does not leach through the soil will be beneficial to reclaiming sodic soils before they reach the point beyond which recovery is no longer possible.

5.3. The relationship between steady state hydraulic conductivity and chemical equilibrium

The highly variable nature of HC results in this study does not allow for a definite relationship between steady state HC and chemical equilibrium to be proposed. From the linear trend lines fitted in the results, it is noted that there is a general trend for decreasing HC over time for the three soils tested. This is a contradiction to what the literature implies that removing Na, Mg and K from the soil and replacing it with Ca should result in a flocculated soil state (stable and therefore maintaining HC), as well as potentially increasing HC through an osmotic effect provided the EC is sufficiently high

The most notable changes in HC came from the Red Ferosol. The general trend is of faster decreasing HC as the EC of the percolating solution increases, suggesting that something beyond what is measured in this study is impacting on the HC, possibly the oxidisation bonds within aggregates are undergoing a breakdown process and settle more slowly than Vertosol and Tenosol soils. Another possible explanation is the gradual sealing of pores located toward the base of soil cores due to turbulent flow washing micro aggregates into percolating solution and subsequent entrainment of these in lower locations. However, the ratio of the core to the ponded solution was 2:1 and turbulent flow was therefore unlikely.

While the trend lines for the Black Vertosol and Brown Tenosol are decreasing, the slopes of the lines are very slight and a steady HC could be assumed. While, this is in contrast to the results of Reading *et al.* (2012), who showed that it may take up to 100 PV’s to reach a steady state, the HC data in this study was highly variable and would benefit from further research. Therefore, in order to assess the importance of chemical exchange equilibrium on HC steady state, more experimentation will be required.

5.4. The appropriateness of leachate electrical conductivity as an indicator for soil chemical equilibrium

Reading *et al.* (2012) suggest that EC is a good measure of attainment of chemical equilibrium, however based on results obtained in this study, there is no direct correlation between EC and ionic exchange equilibrium. Apart from the slightly elevated reading for the first PV recovered for the Black Vertosol and Brown Tenosol, the EC readings appear to be at a steady state for the duration of the PV’s collected.

EC is a measure of the charge in the solution and if electroneutrality is maintained in the soil, theoretically, apart from the first PV when the soil solution soluble load is flushed out, the EC readings of the leachate should remain at a steady state, approximately equal to the EC of the percolating solution (Sparks 2003; Sposito 2008). Therefore, based on the results obtained, EC is not a good measure for chemical equilibrium.

5.5. Future recommendations

After reflecting on the methodology and the aims of this study, there are a number of changes that could be made or variables introduced to obtain a better understanding of the rate that chemical equilibrium is attained in soils.

From the work presented by Reading *et al.* (2012), it appears that bulk density has an impact on all facets used to measure chemical equilibrium, leachate ionic concentration, EC and HC. Further research could be undertaken to assess whether bulk density has an impact on all soil types or just the Vertosol presented by Reading *et al.* (2012). It is noted that this project originally intended to assess the effects of bulk density on ion exchange, but had to be removed from the scope due to time constraints.

Results obtained in this study suggest that for some cations up to 889 PV may of the percolating solution be required to reach the point where total ion replacement has occurred, making the soil a purely Ca based system. While this may not be practical, leaching of a solution with an EC of 2 dS/m for 300 PV, for example, may give an indication of the long term behaviour of a soil subject to sustained leaching, possible in a hot climate using poor quality irrigation water.

This study only considered the use of a Ca dominated percolating solution. Further work may need to be undertaken on the effects of percolation with either Mg or K dominated solutions or even a binary solution (Ca-Mg or Mg-K).

After a soil has reached a homoionic status (Either Ca, Mg or K), subsequent flooding with a Na (or Mg or K, depending on the initial cation) based solution and measuring how many PV's it takes to completely replace all the ions, may give an indication of just how long it actually takes for poor quality irrigation water to irreversibly damage a soil. This is similar to the work performed by the NCEA to assess TEC and would provide further insight into these processes.

Finally, this study should be repeated with a greater soil core to ponded head ratio and highly controlled hydraulic environment to determine the significance of total ion exchange to soil HC steady state conditions. After all, if steady state is achieved prior to full ionic exchange, then further leaching with the same percolating solution will not provide any further meaningful data for TEC analysis.

6. Conclusions

The aim of this study was to investigate how many PV's of solutions of varying EC's were required to pass through a soil core to attain chemical equilibrium. This was in order to understand the effect of EC on the rate chemical equilibrium is attained and the number of PV's required to reach chemical equilibrium.

From experimental investigation, it was observed that increasing the EC of the percolating solution increased the amount of cations replaced in the soil per PV. Furthermore, the rate of ion exchange generally decreases as the number of PV's increases. Throughout all PV, EC was observed to be in a steady state condition, with exception to PV 1 where soil solution solute loads contributed to a higher than initial leachate EC. On this basis, EC was identified as a poor indicator of chemical equilibrium.

While chemical equilibrium was not reached for any soil in study over the 10–30 PV, it was shown through extrapolation that the number of PVs required to obtain complete ionic equilibrium was up to 889. Processes such as exchange models (diffusion or mass transfer), interlayer collapse from 2:1 clays, and macropore preferential flow Vs. micropore flow effects on exchange were considered, but require further investigation. The effect of chemical equilibrium on HC steady state could not be attained due to highly variable HC data. This is an important relationship that needs to be further investigated to fully understand the effects of ionic exchange on current TEC methodologies.

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8. Appendices

8.1. Appendix A: Project Specification

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111/ENG4112 Undergraduate Research Project

Project Specification

Student: Travis Wieck

Topic: Assessing impacts of coal seam gas amended water application: soil chemistry equilibrium as influenced by solution volume and time

Supervisor: Dr John Bennett

Aim: To assess how many pore volumes of water are required to pass through a soil core to attain soil chemical equilibrium. Factors such as bulk density, electrolyte concentration and required pore volumes will be assessed.

Program: Issue B, 10 April 2012

1. Research background information relating to sodicity, salinity, soil chemistry, threshold electrolyte concentration (TEC) and ionic exchange phenomena.
2. Design experimental methodology and procedure for 2 experiments.
    a. Experiment 1
        i. Aim: Investigate the effect of electrolyte concentration and increasing pore volume on a soil's solid and solution chemical equilibrium by analysis of soil leachate.
        ii. This will be performed on 2 to 3 soils to start with, and pending results in this experiment and in experiment 2 and available time, this may be extended to more soils.
    b. Experiment 2
        i. Aim: Investigate changes in soil chemical properties with increasing pore volumes of a $CaCl_2$ solution of a known concentration by increasing bulk density.
        ii. Caveat: The need for this experiment is contingent on results from experiment 1.
        iii. If results from experiment 1 are inconclusive, experiment 2 must be performed for at least 1 soil using at least 1 electrolyte concentration.

3. Analyse data to determine effects of electrolyte concentration, pore volumes and bulk density on soil chemical equilibrium.

Agreed

Student	Supervisor
______________________	______________________
Date	Date
______________________	______________________

8.2. Appendix B: Black Vertosol AAS Data

8.2.1. EC 0.5

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	38.59	129.24	46.86	9.07
Rep1-2	6.82	75.00	13.98	4.45
Rep1-3	3.29	85.46	12.86	4.56
Rep1-4	1.18	57.44	12.32	4.56
Rep1-5	5.88	56.19	12.55	4.78
Rep1-6	0.94	58.07	14.48	5.00
Rep1-7	7.61	55.15	12.07	5.61
Rep1-8	7.84	55.75	16.06	5.00
Rep1-9	0.94	75.41	23.96	5.55
Rep1-10	2.12	40.38	16.34	5.61
Rep2-1	45.65	123.96	53.52	13.52
Rep2-2	9.18	63.80	20.34	10.33
Rep2-3	7.29	59.25	19.59	9.62
Rep2-4	12.47	100.69	14.69	7.26
Rep2-5	13.88	55.46	14.41	7.04
Rep2-6	16.47	48.26	12.05	6.43
Rep2-7	9.41	57.63	14.30	7.20
Rep2-8	8.94	95.65	17.51	10.00
Rep2-9	13.88	52.07	14.68	7.04
Rep2-10	25.65	71.10	13.75	6.93
Rep3-1	36.00	121.24	51.79	11.32
Rep3-2	5.88	65.95	15.66	9.45
Rep3-3	6.35	62.16	13.40	6.82
Rep3-4	3.29	66.28	13.80	7.20
Rep3-5	10.82	60.60	13.18	6.98
Rep3-6	4.94	63.54	12.96	7.09
Rep3-7	1.65	64.48	13.11	7.42
Rep3-8	4.00	64.86	13.35	9.62
Rep3-9	3.53	62.96	13.95	8.74
Rep3-10	5.65	79.58	15.64	8.63
Rep4-1	55.30	148.71	50.13	8.63
Rep4-2	18.35	77.58	21.33	4.78
Rep4-3	15.06	105.87	15.18	4.73
Rep4-4	16.94	64.19	14.33	6.54
Rep4-5	13.88	64.86	15.04	5.55
Rep4-6	11.77	65.68	14.11	5.22
Rep4-7	11.77	61.20	14.81	5.17
Rep4-8	10.59	59.83	14.66	5.66
Rep4-9	9.88	59.18	14.00	5.77
Rep4-10	11.06	55.92	16.71	8.41

AVG-1	43.89	130.79	50.57	10.64
AVG-2	10.06	70.58	17.83	7.26
AVG-3	8.00	78.19	15.26	6.43
AVG-4	8.47	72.15	13.78	6.39
AVG-5	11.12	59.28	13.80	6.09
AVG-6	8.53	58.89	13.40	5.94
AVG-7	7.61	59.61	13.57	6.35
AVG-8	7.84	69.02	15.39	7.57
AVG-9	7.06	62.40	16.65	6.77
AVG-10	11.12	61.75	15.61	7.39

8.2.2. EC 1

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	92.24	220.27	84.69	13.74
Rep1-2	51.30	171.98	56.77	10.94
Rep1-3	58.36	115.36	41.27	6.93
Rep1-4	96.01	83.53	42.29	8.24
Rep1-5	100.71	86.86	36.45	8.02
Rep1-6	62.59	135.58	44.77	7.37
Rep1-7	58.36	95.87	53.92	7.91
Rep1-8	64.24	102.13	59.66	11.54
Rep1-9	72.24	70.35	82.28	12.26
Rep1-10	83.06	32.65	84.04	9.01
Rep2-1	80.01	181.69	86.89	13.80
Rep2-2	36.00	120.23	57.70	9.62
Rep2-3	35.06	166.80	43.54	13.47
Rep2-4	36.00	117.65	50.71	9.84
Rep2-5	46.83	145.41	46.80	12.64
Rep2-6	46.36	95.75	50.97	13.52
Rep2-7	48.94	79.05	61.69	10.83
Rep2-8	56.71	61.44	74.12	11.10
Rep2-9	61.18	43.95	74.72	14.95
Rep2-10	66.12	29.35	72.79	14.24
Rep3-1				
Rep3-2				
Rep3-3				
Rep3-4				
Rep3-5				
Rep3-6				
Rep3-7				
Rep3-8				
Rep3-9				
Rep3-10				

Rep4-1	79.30	189.33	85.96	18.30
Rep4-2	38.36	172.51	53.77	9.45
Rep4-3	37.65	123.14	44.35	12.97
Rep4-4	38.36	124.37	54.97	10.11
Rep4-5	39.77	120.37	47.23	9.89
Rep4-6	40.71	105.36	48.26	12.53
Rep4-7	48.94	88.28	55.12	11.05
Rep4-8	52.00	64.84	59.76	10.77
Rep4-9	58.59	48.81	73.39	10.99
Rep4-10	60.24	34.07	70.30	11.43
AVG-1	83.85	197.10	85.84	15.28
AVG-2	41.89	154.91	56.08	10.00
AVG-3	43.69	135.10	43.05	11.12
AVG-4	56.79	108.52	49.32	9.40
AVG-5	62.44	117.55	43.49	10.19
AVG-6	49.89	112.23	48.00	11.14
AVG-7	52.08	87.73	56.91	9.93
AVG-8	57.65	76.14	64.52	11.14
AVG-9	64.00	54.37	76.80	12.73
AVG-10	69.81	32.02	75.71	11.56

NB: Results from replicate 3 were discarded due to contamination.

8.2.3. EC 2

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	154.36	241.11	157.30	17.97
Rep1-2	88.01	188.66	100.22	15.28
Rep1-3	97.65	220.73	114.86	15.77
Rep1-4	121.19	151.26	110.52	13.52
Rep1-5	116.71	130.93	123.90	13.96
Rep1-6	132.95	82.74	133.67	14.57
Rep1-7	137.66	49.61	149.56	16.05
Rep1-8	141.42	24.77	159.75	15.55
Rep1-9	147.78	15.64	147.58	16.05
Rep1-10	149.66	9.32	150.86	16.65
Rep2-1	179.31	283.54	148.80	18.96
Rep2-2	129.42	191.07	101.43	11.21
Rep2-3	125.42	193.48	118.46	14.73
Rep2-4	132.24	179.74	111.02	11.49
Rep2-5	176.01	122.49	106.46	10.44
Rep2-6	144.95	121.84	128.36	12.64
Rep2-7	150.36	57.44	140.17	13.74
Rep2-8	158.60	31.20	157.30	14.07

Rep2-9	201.90	13.08	140.27	11.60
Rep2-10	221.66	7.08	115.73	12.92
Rep3-1	160.01	282.21	144.77	22.70
Rep3-2	127.07	209.45	117.14	13.69
Rep3-3	132.95	185.84	104.14	13.30
Rep3-4	155.07	154.08	101.91	13.08
Rep3-5	134.60	134.37	115.74	14.90
Rep3-6	146.13	97.20	142.29	19.40
Rep3-7	146.13	65.95	139.49	15.39
Rep3-8	151.78	46.96	145.57	16.27
Rep3-9	174.84	21.83	133.55	16.98
Rep3-10	204.72	9.73	127.46	16.32
Rep4-1	150.13	264.77	144.00	18.03
Rep4-2	102.60	240.29	120.92	15.28
Rep4-3	105.42	184.42	109.04	14.62
Rep4-4	111.54	157.05	123.63	15.23
Rep4-5	119.30	126.90	135.30	17.42
Rep4-6	138.36	86.23	131.62	16.38
Rep4-7	133.19	55.05	136.15	19.35
Rep4-8	145.42	35.06	142.39	19.51
Rep4-9	146.60	21.71	145.23	17.09
Rep4-10	150.36	16.65	160.73	17.59
AVG-1	160.95	267.91	148.72	19.42
AVG-2	111.77	207.37	109.93	13.86
AVG-3	115.36	196.11	111.63	14.61
AVG-4	130.01	160.53	111.77	13.33
AVG-5	136.66	128.67	120.35	14.18
AVG-6	140.60	97.00	133.98	15.75
AVG-7	141.83	57.01	141.34	16.13
AVG-8	149.30	34.50	151.25	16.35
AVG-9	167.78	18.06	141.66	15.43
AVG-10	181.60	10.70	138.69	15.87

8.2.4. EC 4

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	313.43	297.44	208.87	24.57
Rep1-2	272.49	272.19	200.05	25.06
Rep1-3	295.55	209.79	200.34	23.80
Rep1-4	330.61	148.85	204.00	23.25
Rep1-5	381.20	84.38	195.39	22.32
Rep1-6	344.26	48.55	214.26	28.80
Rep1-7	328.73	20.70	223.50	26.49
Rep1-8	339.08	11.32	219.59	26.88

Rep1-9	331.08	7.16	221.04	25.78
Rep1-10	348.50	6.65	221.34	30.29
Rep2-1	325.91	383.79	213.98	21.55
Rep2-2	259.78	320.57	198.30	17.97
Rep2-3	315.32	238.84	193.46	15.55
Rep2-4	320.26	144.88	199.50	16.76
Rep2-5	407.09	73.32	189.14	12.81
Rep2-6	343.55	42.53	213.73	15.77
Rep2-7	309.67	17.37	213.70	16.49
Rep2-8	323.55	9.37	216.61	21.77
Rep2-9	315.08	6.43	217.24	17.75
Rep2-10	368.26	4.55	222.34	21.33
Rep3-1	319.55	349.24	216.18	24.29
Rep3-2	281.67	263.08	187.70	16.05
Rep3-3	268.02	244.43	203.38	19.02
Rep3-4	286.61	166.80	210.04	20.39
Rep3-5	308.02	94.57	215.10	19.68
Rep3-6	348.73	34.14	210.00	21.55
Rep3-7	311.08	16.31	221.92	19.46
Rep3-8	371.56	8.34	199.99	17.59
Rep3-9	321.20	7.66	221.84	19.29
Rep3-10	341.67	5.88	215.63	18.63
Rep4-1	314.85	361.58	211.17	26.71
Rep4-2	268.73	262.75	203.30	23.96
Rep4-3	280.02	194.90	199.77	25.45
Rep4-4	308.49	132.66	207.82	23.58
Rep4-5	323.32	78.35	210.49	25.89
Rep4-6	323.79	47.97	213.37	21.99
Rep4-7	333.67	25.06	216.16	23.36
Rep4-8	318.85	12.82	213.28	21.82
Rep4-9	333.20	9.35	219.29	27.15
Rep4-10	348.50	5.90	221.84	22.98
AVG-1	318.43	348.01	212.55	24.28
AVG-2	270.67	279.65	197.34	20.76
AVG-3	289.73	221.99	199.24	20.96
AVG-4	311.49	148.30	205.34	21.00
AVG-5	354.91	82.65	202.53	20.17
AVG-6	340.08	43.30	212.84	22.03
AVG-7	320.79	19.86	218.82	21.45
AVG-8	338.26	10.46	212.37	22.01
AVG-9	325.14	7.65	219.85	22.49
AVG-10	351.73	5.75	220.28	23.30

8.2.5. EC 8

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	598.40	399.14	247.81	31.11
Rep1-2	550.39	328.96	247.08	34.19
Rep1-3	595.57	196.32	248.71	27.65
Rep1-4	749.94	87.87	243.95	28.20
Rep1-5	868.30	31.15	238.53	20.78
Rep1-6	679.34	18.82	249.66	33.36
Rep1-7	674.87	11.59	250.96	28.58
Rep1-8	691.58	9.35	249.55	32.21
Rep1-9	720.05	10.07	248.90	36.77
Rep1-10	734.64	9.40	243.32	31.93
Rep2-1	680.99	429.60	250.23	40.07
Rep2-2	621.93	338.16	251.51	32.92
Rep2-3	656.75	210.44	249.79	31.60
Rep2-4	752.29	106.23	250.34	34.96
Rep2-5	815.35	43.71	249.18	34.08
Rep2-6	841.71	19.71	248.51	27.59
Rep2-7	724.52	9.47	253.22	30.56
Rep2-8	805.00	6.34	253.62	29.57
Rep2-9	881.48	6.14	247.10	27.32
Rep2-10	866.65	6.58	247.68	31.00
Rep3-1	648.52	440.63	250.44	36.00
Rep3-2	578.39	351.82	245.70	25.06
Rep3-3	577.45	222.77	248.86	28.75
Rep3-4	620.99	106.33	251.88	29.79
Rep3-5	705.93	41.92	249.16	27.87
Rep3-6	688.99	16.46	247.80	26.93
Rep3-7	679.58	8.05	250.91	24.73
Rep3-8	679.11	6.58	250.31	30.94
Rep3-9	716.52	5.81	249.73	26.44
Rep3-10	756.76	5.06	246.63	30.78
Rep4-1	642.63	417.16	252.74	36.50
Rep4-2	576.51	347.22	249.36	36.22
Rep4-3	616.04	196.49	249.35	37.16
Rep4-4	652.05	107.92	251.23	31.16
Rep4-5	670.40	51.32	253.14	35.45
Rep4-6	655.58	24.72	252.69	29.79
Rep4-7	679.11	16.65	249.94	32.98
Rep4-8	730.64	13.37	250.29	29.13
Rep4-9	773.00	13.16	247.81	33.86
Rep4-10	775.82	12.31	245.25	30.29
AVG-1	642.63	421.63	250.31	35.92
AVG-2	581.81	341.54	248.41	32.10

AVG-3	611.46	206.50	249.18	31.29
AVG-4	693.81	102.09	249.35	31.03
AVG-5	765.00	42.03	247.50	29.54
AVG-6	716.40	19.93	249.67	29.42
AVG-7	689.52	11.44	251.26	29.21
AVG-8	726.58	8.91	250.94	30.46
AVG-9	772.76	8.79	248.38	31.10
AVG-10	783.47	8.34	245.72	31.00

8.3. Appendix C: Red Ferosol AAS Data

8.3.1. EC 0.5

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	62.15	15.09	14.61	6.74
Rep1-2	61.33	11.34	17.84	6.28
Rep1-3	71.21	10.87	19.15	5.87
Rep1-4	69.56	11.94	13.35	5.74
Rep1-5	57.62	9.02	12.52	5.57
Rep1-6	55.15	7.19	12.17	5.45
Rep1-7	60.09	6.83	12.29	5.45
Rep1-8	62.56	6.83	16.99	6.86
Rep1-9	63.39	6.54	16.88	5.91
Rep1-10	61.74	6.31	11.21	5.62
Rep2-1	118.13	17.22	15.01	8.28
Rep2-2	119.36	13.42	13.64	5.12
Rep2-3	121.01	6.63	14.65	6.78
Rep2-4	105.78	6.75	12.12	4.62
Rep2-5	107.43	6.64	11.69	4.45
Rep2-6	113.19	3.98	11.21	4.20
Rep2-7	108.66	6.33	11.31	4.28
Rep2-8	108.66	3.39	12.11	4.83
Rep2-9	112.37	3.22	10.87	6.24
Rep2-10	110.72	5.30	10.73	4.28
Rep3-1	77.38	11.02	14.34	5.87
Rep3-2	70.80	8.82	12.51	7.40
Rep3-3	78.62	7.85	12.53	5.45
Rep3-4	60.09	5.89	12.44	6.99
Rep3-5	76.56	5.25	11.28	6.95
Rep3-6	75.73	4.53	8.62	4.95
Rep3-7	76.97	3.36	11.12	6.20
Rep3-8	81.36	2.51	10.69	4.33
Rep3-9	71.21	4.81	13.54	4.78
Rep3-10	88.49	5.40	11.52	4.78
Rep4-1	66.68	14.85	17.10	7.57
Rep4-2	72.03	11.44	16.17	6.53
Rep4-3	70.38	8.57	15.53	6.28
Rep4-4	73.68	7.96	15.47	5.99
Rep4-5	70.38	7.14	15.19	7.28
Rep4-6	70.38	5.96	14.87	5.32
Rep4-7	66.68	5.25	13.42	5.28
Rep4-8	72.85	4.84	12.48	5.08
Rep4-9	76.15	4.66	12.86	5.08
Rep4-10	75.73	4.60	12.61	5.20

AVG-1	81.09	14.54	15.27	7.11
AVG-2	80.88	11.26	15.04	6.33
AVG-3	85.30	8.48	15.47	6.09
AVG-4	77.28	8.13	13.35	5.83
AVG-5	78.00	7.01	12.67	6.06
AVG-6	78.62	5.41	11.72	4.98
AVG-7	78.10	5.44	12.03	5.30
AVG-8	81.36	4.39	13.07	5.27
AVG-9	80.78	4.81	13.54	5.50
AVG-10	84.17	5.40	11.52	4.97

8.3.2. EC 1

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	199.63	16.90	38.25	10.69
Rep1-2	180.69	13.35	35.09	9.36
Rep1-3	189.75	14.33	28.86	7.11
Rep1-4	199.63	10.15	27.83	6.78
Rep1-5	214.44	8.60	25.96	6.86
Rep1-6	181.93	9.66	23.20	7.70
Rep1-7	186.46	9.14	21.28	6.28
Rep1-8	218.56	7.19	27.65	7.74
Rep1-9	192.22	6.25	24.89	5.82
Rep1-10	214.44	6.20	19.62	6.61
Rep2-1	213.62	15.39	28.21	7.70
Rep2-2	228.03	11.59	29.65	6.86
Rep2-3	223.09	14.06	27.72	6.20
Rep2-4	225.97	12.62	25.61	6.32
Rep2-5	225.15	7.96	30.03	8.32
Rep2-6	231.73	6.45	22.46	5.91
Rep2-7	226.38	7.02	25.43	5.03
Rep2-8	240.79	5.13	26.17	5.16
Rep2-9	255.60	6.63	22.75	5.12
Rep2-10	249.02	4.39	24.25	6.49
Rep3-1	184.40	18.55	29.71	7.90
Rep3-2	170.40	12.18	29.22	9.40
Rep3-3	200.04	10.25	31.38	7.03
Rep3-4	190.16	8.78	25.83	6.74
Rep3-5	176.58	6.52	25.00	6.12
Rep3-6	198.80	6.31	22.66	6.45
Rep3-7	190.57	5.05	22.82	7.90
Rep3-8	185.63	3.93	27.78	6.53
Rep3-9	202.10	4.28	21.18	6.07
Rep3-10	204.15	3.56	18.57	5.70

Rep4-1	141.18	18.64	28.65	8.61
Rep4-2	136.24	14.20	27.33	7.78
Rep4-3	144.88	12.00	26.30	8.07
Rep4-4	146.94	10.52	25.91	7.65
Rep4-5	143.65	8.75	23.65	7.07
Rep4-6	157.23	8.02	23.51	7.24
Rep4-7	163.82	7.70	21.93	6.91
Rep4-8	153.12	5.89	19.81	6.03
Rep4-9	154.35	5.58	19.61	6.28
Rep4-10	160.11	5.36	19.79	6.16
AVG-1	184.71	17.37	31.21	8.73
AVG-2	178.84	12.83	30.32	8.35
AVG-3	189.44	12.66	28.56	7.10
AVG-4	190.67	10.52	26.30	6.87
AVG-5	189.95	7.96	26.16	7.09
AVG-6	192.42	7.61	22.96	6.82
AVG-7	191.81	7.23	22.87	6.53
AVG-8	199.52	5.54	25.35	6.36
AVG-9	201.07	5.69	22.10	5.82
AVG-10	206.93	4.88	20.56	6.24

8.3.3. EC 2

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	414.89	19.89	50.16	9.28
Rep1-2	470.46	16.84	51.88	9.15
Rep1-3	436.71	11.53	42.86	9.19
Rep1-4	436.30	11.74	39.59	6.99
Rep1-5	457.29	10.67	37.66	7.40
Rep1-6	413.25	6.54	35.86	6.57
Rep1-7	470.46	6.27	32.26	7.57
Rep1-8	480.34	7.05	31.63	6.24
Rep1-9	419.01	6.40	26.74	5.99
Rep1-10	506.68	6.20	31.25	6.74
Rep2-1	410.37	26.70	57.12	13.23
Rep2-2	458.93	19.40	49.84	9.78
Rep2-3	482.40	15.16	51.14	9.65
Rep2-4	479.93	12.06	40.55	9.11
Rep2-5	484.87	11.99	38.25	9.44
Rep2-6	468.40	11.85	33.43	9.86
Rep2-7	492.27	10.61	37.43	7.24
Rep2-8	498.45	8.91	30.67	8.40
Rep2-9	503.39	8.37	33.02	7.07
Rep2-10	502.56	7.95	28.33	6.86

Rep3-1	422.30	22.26	49.17	10.98
Rep3-2	466.34	17.48	47.18	10.65
Rep3-3	428.06	12.09	36.97	7.24
Rep3-4	499.68	10.91	30.52	8.86
Rep3-5	426.83	9.08	28.94	6.74
Rep3-6	405.02	7.36	33.89	6.61
Rep3-7	425.18	7.22	34.61	6.07
Rep3-8	474.99	4.92	27.77	6.32
Rep3-9	513.68	4.40	40.15	6.41
Rep3-10	498.86	5.72	29.90	6.32
Rep4-1	246.96	20.20	40.24	11.19
Rep4-2	291.83	16.21	39.84	10.94
Rep4-3	326.81	14.33	39.97	11.19
Rep4-4	274.13	11.53	31.35	9.36
Rep4-5	330.52	11.03	33.80	9.61
Rep4-6	325.16	9.87	31.57	9.11
Rep4-7	317.34	8.19	29.23	8.03
Rep4-8	314.87	7.20	27.33	7.82
Rep4-9	335.87	6.98	27.40	7.86
Rep4-10	326.81	6.05	24.37	7.20
AVG-1	373.63	22.26	49.17	11.17
AVG-2	421.89	17.48	47.18	10.13
AVG-3	418.50	13.28	42.73	9.32
AVG-4	422.51	11.56	35.50	8.58
AVG-5	424.87	10.69	34.66	8.30
AVG-6	402.96	8.90	33.69	8.04
AVG-7	426.32	8.07	33.38	7.23
AVG-8	442.16	7.02	29.35	7.20
AVG-9	442.99	6.54	31.83	6.83
AVG-10	458.73	6.48	28.46	6.78

8.3.4. EC 4

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	908.40	22.66	69.93	13.23
Rep1-2	986.61	19.24	66.70	13.27
Rep1-3	961.50	15.60	58.27	13.02
Rep1-4	1051.23	12.92	60.34	10.90
Rep1-5	1008.01	13.36	54.25	10.77
Rep1-6	1054.52	11.37	49.32	11.23
Rep1-7	1005.95	11.55	46.57	9.36
Rep1-8	1061.93	9.26	42.83	8.57
Rep1-9	968.91	8.10	35.19	8.07
Rep1-10	954.09	8.04	32.82	8.03

Rep2-1	958.21	27.09	94.59	14.73
Rep2-2	968.09	18.66	85.24	13.02
Rep2-3	983.31	14.39	77.05	14.43
Rep2-4	1036.82	13.38	68.80	11.27
Rep2-5	1013.36	9.26	64.59	10.86
Rep2-6	1076.75	8.10	54.50	9.65
Rep2-7	1046.70	6.42	51.01	11.02
Rep2-8	1032.29	5.25	48.87	8.86
Rep2-9	1073.87	5.24	46.75	10.15
Rep2-10	1088.68	6.16	43.11	11.02
Rep3-1	836.78	27.62	63.13	14.10
Rep3-2	779.57	17.68	65.75	11.40
Rep3-3	852.84	15.94	57.43	11.44
Rep3-4	953.68	13.27	50.25	10.03
Rep3-5	966.85	11.32	48.61	10.52
Rep3-6	916.22	9.44	44.36	8.11
Rep3-7	979.61	8.37	40.61	9.48
Rep3-8	934.33	6.93	45.58	8.57
Rep3-9	935.16	6.16	40.17	6.86
Rep3-10	1021.59	5.90	37.10	7.70
Rep4-1	601.76	27.23	67.84	15.56
Rep4-2	646.62	21.94	63.94	14.56
Rep4-3	616.99	17.16	58.21	13.44
Rep4-4	617.81	14.23	52.27	11.90
Rep4-5	680.79	12.91	51.77	11.98
Rep4-6	577.06	9.97	41.39	9.73
Rep4-7	565.95	8.84	36.50	9.03
Rep4-8	657.33	8.61	40.68	11.11
Rep4-9	717.42	8.28	38.56	9.73
Rep4-10	660.21	6.57	35.38	9.98
AVG-1	826.29	26.15	73.87	14.40
AVG-2	845.22	19.38	70.41	13.06
AVG-3	853.66	15.77	62.74	13.08
AVG-4	914.89	13.45	57.91	11.02
AVG-5	917.25	11.71	54.81	11.03
AVG-6	906.14	9.72	47.39	9.68
AVG-7	899.55	8.79	43.67	9.72
AVG-8	921.47	7.51	44.49	9.28
AVG-9	923.84	6.94	40.17	8.70
AVG-10	931.14	6.67	37.10	9.18

8.3.5. EC 8

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*

Rep1-1	1699.50	25.70	104.58	14.93
Rep1-2	1955.93	22.14	107.17	14.60
Rep1-3	1915.59	17.83	88.36	14.81
Rep1-4	1988.03	14.44	81.85	14.14
Rep1-5	2070.35	11.59	75.09	13.52
Rep1-6	2181.48	10.91	71.08	11.77
Rep1-7	2086.40	10.49	68.15	11.27
Rep1-8	2146.91	8.35	65.11	11.27
Rep1-9	2172.43	6.89	57.24	10.73
Rep1-10	2093.81	5.87	52.15	9.11
Rep2-1	2081.88	21.57	90.21	12.81
Rep2-2	2180.25	18.01	89.80	12.06
Rep2-3	2111.51	13.97	72.47	10.94
Rep2-4	2182.31	10.93	73.29	10.11
Rep2-5	2141.56	10.84	58.96	10.44
Rep2-6	2158.85	8.37	51.66	10.11
Rep2-7	2220.59	9.59	50.97	8.57
Rep2-8	2196.71	7.19	46.49	7.40
Rep2-9	2087.23	6.45	41.26	6.91
Rep2-10	2141.97	5.86	39.59	7.16
Rep3-1	1688.80	22.22	68.85	12.19
Rep3-2	2069.94	19.16	79.99	13.15
Rep3-3	1735.72	12.98	49.59	9.90
Rep3-4	1985.97	13.64	54.87	11.59
Rep3-5	1570.67	7.46	49.09	9.07
Rep3-6	1981.03	8.70	44.12	8.90
Rep3-7	1934.52	7.32	34.97	8.57
Rep3-8	1953.05	6.76	43.60	7.57
Rep3-9	1592.07	5.75	59.79	6.57
Rep3-10	2195.48	5.61	52.20	8.65
Rep4-1	2018.08	32.48	37.28	19.80
Rep4-2	2025.08	25.39	42.99	16.89
Rep4-3	1773.18	22.14	69.07	13.19
Rep4-4	1787.58	15.56	73.04	10.52
Rep4-5	1647.64	11.87	61.06	10.15
Rep4-6	2036.60	11.06	66.03	9.82
Rep4-7	1798.28	7.11	49.05	8.24
Rep4-8	1992.15	6.16	48.92	8.65
Rep4-9	1682.21	3.78	80.86	7.24
Rep4-10	1804.87	3.75	64.87	7.57
AVG-1	1872.06	25.49	75.23	14.93
AVG-2	2057.80	21.18	79.99	14.17
AVG-3	1884.00	16.73	69.87	12.21
AVG-4	1985.97	13.64	70.76	11.59
AVG-5	1857.55	10.44	61.05	10.79
AVG-6	2089.49	9.76	58.22	10.15

AVG-7	2009.95	8.63	50.78	9.16
AVG-8	2072.20	7.12	51.03	8.73
AVG-9	1883.49	5.72	59.79	7.86
AVG-10	2059.03	5.27	52.20	8.12

8.4. Appendix D: Brown Tenosol AAS Data

8.4.1. EC 0.5

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	77.06	12.86	13.09	10.89
Rep1-2	55.97	7.66	9.63	9.74
Rep1-3	55.97	7.06	15.42	9.05
Rep1-4	43.80	15.60	16.00	8.99
Rep1-5	51.91	6.61	16.70	12.68
Rep1-6	56.78	7.32	10.16	12.39
Rep1-7	62.46	7.46	17.13	11.93
Rep1-8	51.10	7.80	16.65	10.72
Rep1-9	73.00	7.97	16.53	9.97
Rep1-10	73.81	7.80	10.01	9.39
Rep1-11	55.97	1.67	15.70	3.00
Rep1-12	51.10	2.09	17.25	5.13
Rep1-13	45.42	1.58	17.33	4.32
Rep1-14	45.42	1.55	17.68	3.05
Rep1-15	65.70	1.92	13.69	3.05
Rep1-16	65.70	1.86	11.79	2.82
Rep1-17	53.53	2.06	12.81	2.31
Rep1-18	69.76	1.98	14.57	1.10
Rep1-19	72.19	1.84	15.10	1.79
Rep1-20	69.76	2.26	14.85	1.38
Rep1-21	89.22	1.70	10.48	4.03
Rep1-22	92.47	1.61	10.86	4.03
Rep1-23	81.92	1.81	9.40	3.92
Rep1-24	102.20	1.89	7.07	3.86
Rep1-25	100.58	1.86	6.92	3.57
Rep1-26	85.17	1.89	5.79	3.52
Rep1-27	100.58	2.03	4.76	3.52
Rep1-28	104.63	2.03	4.14	3.46
Rep1-29	86.79	2.09	3.54	3.40
Rep1-30	99.77	1.86	2.76	3.46
Rep2-1	67.32	9.07	12.01	21.50
Rep2-2	43.80	6.24	9.91	15.85
Rep2-3	55.16	6.47	9.18	9.85
Rep2-4	50.29	6.19	10.16	14.47
Rep2-5	45.42	8.19	11.39	9.28
Rep2-6	48.67	6.39	9.05	13.49
Rep2-7	55.16	6.39	11.16	12.33
Rep2-8	61.64	15.57	8.88	9.97
Rep2-9	47.04	6.58	14.02	8.30
Rep2-10	64.89	6.33	9.00	9.80

Rep2-11	42.99	2.32	11.86	6.57
Rep2-12	47.86	2.01	10.03	6.05
Rep2-13	73.00	2.29	14.75	5.42
Rep2-14	50.29	2.12	15.05	4.55
Rep2-15	54.34	2.26	10.48	6.45
Rep2-16	78.68	2.37	14.77	3.46
Rep2-17	73.81	2.68	13.52	3.00
Rep2-18	54.34	2.32	9.78	2.59
Rep2-19	60.02	2.85	12.36	2.54
Rep2-20	73.81	2.66	12.19	3.52
Rep2-21	95.71	2.03	11.41	4.15
Rep2-22	95.71	2.15	10.96	4.03
Rep2-23	96.52	2.12	10.56	3.92
Rep2-24	85.17	2.23	9.40	3.98
Rep2-25	95.71	2.26	7.97	3.92
Rep2-26	96.52	2.29	6.90	3.92
Rep2-27	98.96	2.35	6.07	3.46
Rep2-28	102.20	2.26	5.14	3.69
Rep2-29	101.39	2.63	5.27	3.52
Rep2-30	113.56	3.98	5.67	3.69
Rep3-1	73.81	9.78	24.22	
Rep3-2	34.88	5.68	13.29	
Rep3-3	30.82	4.18	12.09	
Rep3-4	35.69	3.90	12.31	
Rep3-5	33.26	3.53	12.94	
Rep3-6	41.37	3.62	12.69	
Rep3-7	53.53	4.58	11.86	
Rep3-8	42.99	3.79	12.46	
Rep3-9	51.10	4.13	11.66	
Rep3-10	51.10	4.38	12.89	
Rep3-11	51.10	3.76	13.14	
Rep3-12	62.46	3.45	14.87	
Rep3-13	78.68	3.79	15.25	
Rep3-14	63.27	3.70	15.55	
Rep3-15	62.46	4.07	10.58	
Rep3-16	79.49	3.98	14.82	
Rep3-17	65.70	3.93	10.43	
Rep3-18	68.13	4.07	14.39	
Rep3-19	84.36	4.13	9.28	
Rep3-20	77.87	4.18	9.35	
Rep3-21	35.69	2.01	11.74	
Rep3-22	42.18	1.98	8.73	
Rep3-23	51.10	2.06	8.33	
Rep3-24	53.53	2.40	7.25	
Rep3-25	79.49	2.20	6.42	
Rep3-26	57.59	2.85	6.87	

Rep3-27	60.83	2.54	5.69	
Rep3-28	88.41	2.80	4.74	
Rep3-29	76.25	3.08	4.31	
Rep3-30	62.46	2.97	3.06	
Rep4-1	90.03	9.78	20.29	18.61
Rep4-2	51.91	6.27	10.81	15.33
Rep4-3	51.91	4.49	15.77	13.54
Rep4-4	58.40	4.21	12.09	8.18
Rep4-5	46.23	3.98	17.08	11.24
Rep4-6	60.02	5.03	12.04	7.26
Rep4-7	61.64	5.00	11.91	6.92
Rep4-8	55.16	5.17	13.07	8.53
Rep4-9	68.13	4.41	13.09	6.51
Rep4-10	57.59	5.26	18.68	6.92
Rep4-11	52.72	1.44	13.19	5.13
Rep4-12	33.26	0.93	19.28	4.67
Rep4-13	34.07	1.89	18.13	4.26
Rep4-14	47.04	2.60	17.91	2.88
Rep4-15	29.20	1.53	10.63	4.84
Rep4-16	47.04	1.53	11.96	2.94
Rep4-17	25.14	1.86	14.14	3.46
Rep4-18	42.18	2.74	7.75	3.40
Rep4-19	44.61	3.14	11.18	3.00
Rep4-20	41.37	2.46	9.50	3.28
Rep4-21	69.76	0.93	6.82	2.88
Rep4-22	85.98	0.71	6.90	2.71
Rep4-23	89.22	0.73	4.11	2.65
Rep4-24	92.47	0.90	3.08	2.54
Rep4-25	91.66	1.27	4.49	2.54
Rep4-26	91.66	1.02	2.51	2.88
Rep4-27	94.09	1.07	2.83	2.94
Rep4-28	90.85	1.64	1.55	2.42
Rep4-29	94.90	1.64	1.81	2.48
Rep4-30	91.66	1.41	1.18	2.88
AVG-1	77.06	10.37	17.40	17.00
AVG-2	46.64	6.46	10.91	13.64
AVG-3	48.46	5.55	13.12	10.82
AVG-4	47.04	7.47	12.64	10.55
AVG-5	44.21	5.58	14.53	11.06
AVG-6	51.71	5.59	10.98	11.05
AVG-7	58.20	5.86	13.02	10.39
AVG-8	52.72	8.08	12.76	9.74
AVG-9	59.82	5.77	13.82	8.26
AVG-10	61.85	5.94	12.65	8.70
AVG-11	50.69	2.30	13.47	4.90
AVG-12	48.67	2.12	15.36	5.28

AVG-13	57.79	2.39	16.36	4.67
AVG-14	51.51	2.49	16.54	3.50
AVG-15	52.93	2.44	11.35	4.78
AVG-16	67.73	2.44	13.33	3.07
AVG-17	54.55	2.63	12.73	2.92
AVG-18	58.60	2.78	11.62	2.36
AVG-19	65.29	2.99	11.98	2.44
AVG-20	65.70	2.89	11.47	2.73
AVG-21	72.59	1.67	10.11	3.69
AVG-22	79.08	1.61	9.36	3.59
AVG-23	79.69	1.68	8.10	3.50
AVG-24	83.34	1.86	6.70	3.46
AVG-25	91.86	1.90	6.45	3.34
AVG-26	82.73	2.01	5.52	3.44
AVG-27	88.61	2.00	4.84	3.30
AVG-28	96.52	2.18	3.89	3.19
AVG-29	89.83	2.36	3.73	3.13
AVG-30	91.86	2.56	3.17	3.34

Note: Potassium measurements for Replicate 3 have been omitted due to bad readings from the AAS.

8.4.2. EC 1

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	63.27	9.61	32.32	28.53
Rep1-2	42.18	5.48	38.02	16.42
Rep1-3	48.67	5.00	35.79	16.54
Rep1-4	85.17	4.61	34.73	15.56
Rep1-5	123.29	4.55	30.64	15.39
Rep1-6	137.89	10.77	33.00	13.43
Rep1-7	156.55	4.58	26.81	10.78
Rep1-8	144.38	5.31	25.88	9.22
Rep1-9	180.88	4.55	24.12	7.55
Rep1-10	192.23	4.89	25.60	6.92
Rep1-11	150.06	2.77	17.38	13.02
Rep1-12	176.01	2.66	15.87	14.58
Rep1-13	153.30	2.77	14.04	10.03
Rep1-14	165.47	2.97	9.55	9.05
Rep1-15	167.90	3.00	8.45	8.36
Rep1-16	168.71	2.94	6.82	9.51
Rep1-17	175.20	3.02	5.22	6.86
Rep1-18	193.05	2.91	4.34	7.26

Rep1-19	176.82	2.97	3.81	6.97
Rep1-20	181.69	3.39	3.18	6.11
Rep1-21	188.18	0.34	3.24	1.84
Rep1-22	193.86	0.71	2.13	2.19
Rep1-23	159.79	0.62	1.60	2.13
Rep1-24	173.58	1.38	1.53	2.42
Rep1-25	171.96	0.99	1.38	1.73
Rep1-26	171.96	1.07	1.20	1.79
Rep1-27	178.45	0.99	1.63	1.84
Rep1-28	180.07	1.33	0.95	3.05
Rep1-29	188.99	1.27	0.85	2.02
Rep1-30	184.93	1.47	0.78	2.02
Rep2-1	115.18	10.62	31.42	31.35
Rep2-2	117.61	4.21	35.86	16.37
Rep2-3	123.29	4.21	35.38	15.79
Rep2-4	132.21	4.38	26.98	11.99
Rep2-5	137.08	3.33	24.07	12.62
Rep2-6	137.89	4.86	23.05	10.66
Rep2-7	134.65	3.62	22.22	9.16
Rep2-8	159.79	4.24	22.87	7.38
Rep2-9	159.79	4.44	19.64	6.40
Rep2-10	144.38	5.09	25.00	6.51
Rep2-11	141.95	2.12	19.21	15.96
Rep2-12	142.76	3.08	19.08	9.97
Rep2-13	180.07	2.20	14.14	12.62
Rep2-14	154.11	2.18	10.16	8.99
Rep2-15	168.71	2.54	9.13	8.41
Rep2-16	200.35	2.74	7.25	9.62
Rep2-17	199.53	2.32	5.27	7.66
Rep2-18	176.01	2.71	4.56	6.97
Rep2-19	171.96	2.43	3.84	6.80
Rep2-20	173.58	2.80	3.24	6.57
Rep2-21	183.31	1.44	1.81	2.71
Rep2-22	184.93	1.61	1.50	2.88
Rep2-23	188.18	1.81	1.30	2.71
Rep2-24	187.37	1.81	0.83	2.77
Rep2-25	165.47	1.95	1.10	2.77
Rep2-26	186.56	1.95	0.75	2.71
Rep2-27	231.17	2.06	1.05	2.82
Rep2-28	199.53	2.26	0.68	2.59
Rep2-29	196.29	2.06	0.93	2.54
Rep2-30	216.57	2.26	0.93	2.48
Rep3-1	121.67	15.71	41.33	
Rep3-2	97.33	11.16	33.50	
Rep3-3	101.39	8.48	44.26	
Rep3-4	107.88	10.54	33.98	

Rep3-5	111.93	8.50	31.45	
Rep3-6	120.86	8.17	29.37	
Rep3-7	124.10	7.80	28.76	
Rep3-8	158.17	8.25	27.48	
Rep3-9	139.51	7.91	26.28	
Rep3-10	173.58	11.87	28.76	
Rep3-11	163.03	1.89	17.43	
Rep3-12	147.62	1.81	17.48	
Rep3-13	176.82	2.09	13.09	
Rep3-14	154.92	2.03	7.65	
Rep3-15	179.26	2.18	6.34	
Rep3-16	184.93	2.15	3.29	
Rep3-17	190.61	2.32	2.66	
Rep3-18	194.67	2.26	2.51	
Rep3-19	199.53	2.29	1.53	
Rep3-20	161.41	2.63	1.25	
Rep3-21	227.92	2.29	1.20	
Rep3-22	198.72	2.49	1.15	
Rep3-23	206.83	2.51	1.13	
Rep3-24	227.11	2.63	0.93	
Rep3-25	227.11	2.54	0.65	
Rep3-26	228.73	2.68	0.88	
Rep3-27	235.22	2.68	0.78	
Rep3-28	226.30	2.74	0.75	
Rep3-29	231.17	2.57	0.78	
Rep3-30	231.98	2.54	0.78	
Rep4-1	141.95	9.32	46.32	15.68
Rep4-2	123.29	3.56	39.70	14.47
Rep4-3	130.59	4.80	39.30	10.49
Rep4-4	142.76	2.77	38.07	16.37
Rep4-5	143.57	2.88	34.46	13.20
Rep4-6	141.95	2.18	27.31	11.81
Rep4-7	154.92	2.77	32.20	6.86
Rep4-8	162.22	3.05	31.07	7.38
Rep4-9	167.09	3.42	22.22	5.71
Rep4-10	172.77	2.49	26.38	4.32
Rep4-11	129.78	3.48	20.89	5.99
Rep4-12	106.26	3.28	16.33	3.52
Rep4-13	121.67	3.11	11.81	3.86
Rep4-14	132.21	3.05	10.23	3.57
Rep4-15	128.97	3.36	7.62	4.15
Rep4-16	138.70	3.39	4.04	3.80
Rep4-17	162.22	3.50	4.84	2.94
Rep4-18	143.57	3.81	4.04	3.34
Rep4-19	136.27	3.48	3.56	2.59
Rep4-20	155.73	3.67	3.49	2.94

Rep4-21	219.00	2.83	0.93	3.00
Rep4-22	231.17	3.00	1.03	3.28
Rep4-23	227.11	3.31	1.00	7.95
Rep4-24	232.79	3.19	0.85	3.75
Rep4-25	232.79	3.05	0.75	2.77
Rep4-26	219.00	3.25	0.53	2.71
Rep4-27	231.17	3.45	0.70	2.71
Rep4-28	229.55	3.70	0.68	2.59
Rep4-29	224.68	3.53	0.78	2.65
Rep4-30	234.41	3.36	0.95	2.88
AVG-1	110.51	11.32	37.85	25.18
AVG-2	95.10	6.10	36.77	15.75
AVG-3	100.98	5.62	38.68	14.27
AVG-4	117.00	5.57	33.44	14.64
AVG-5	128.97	4.82	30.16	13.74
AVG-6	134.65	6.49	28.18	11.97
AVG-7	142.55	4.69	27.50	8.93
AVG-8	156.14	5.21	26.83	7.99
AVG-9	161.82	5.08	23.06	6.55
AVG-10	170.74	6.08	26.44	5.92
AVG-11	146.20	2.56	18.73	11.66
AVG-12	143.16	2.71	17.19	9.36
AVG-13	157.96	2.54	13.27	8.84
AVG-14	151.68	2.56	9.40	7.20
AVG-15	161.21	2.77	7.89	6.97
AVG-16	173.17	2.80	5.35	7.65
AVG-17	181.89	2.79	4.50	5.82
AVG-18	176.82	2.92	3.86	5.86
AVG-19	171.15	2.79	3.18	5.46
AVG-20	168.10	3.12	2.79	5.21
AVG-21	204.60	1.72	1.79	2.52
AVG-22	202.17	1.95	1.45	2.79
AVG-23	195.48	2.06	1.26	4.26
AVG-24	205.21	2.25	1.03	2.98
AVG-25	199.33	2.13	0.97	2.42
AVG-26	201.56	2.24	0.84	2.40
AVG-27	219.00	2.30	1.04	2.46
AVG-28	208.86	2.51	0.76	2.75
AVG-29	210.28	2.36	0.83	2.40
AVG-30	216.97	2.41	0.86	2.46

8.4.3. EC 2

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*

Rep1-1	249.82	14.44	89.15	44.66
Rep1-2	257.94	7.35	81.98	30.08
Rep1-3	287.95	6.70	63.07	27.72
Rep1-4	323.64	5.76	58.58	22.42
Rep1-5	362.57	5.85	40.32	16.77
Rep1-6	390.15	5.93	38.29	12.79
Rep1-7	410.43	6.47	23.92	10.03
Rep1-8	378.79	6.33	16.40	6.92
Rep1-9	425.03	6.89	10.13	5.99
Rep1-10	442.87	7.46	8.30	6.40
Rep1-11	366.62	2.94	4.06	5.94
Rep1-12	399.88	2.80	3.66	5.47
Rep1-13	418.54	3.00	2.88	5.19
Rep1-14	392.58	2.71	2.26	4.67
Rep1-15	424.21	2.85	2.01	4.50
Rep1-16	443.68	2.77	3.24	4.32
Rep1-17	369.06	3.08	1.98	3.86
Rep1-18	442.06	2.57	1.88	3.92
Rep1-19	419.35	1.36	1.63	3.57
Rep1-20	429.08	1.95	2.23	3.57
Rep1-21	475.31	3.81	0.95	3.11
Rep1-22	493.97	3.76	0.93	3.00
Rep1-23	434.76	3.70	0.65	2.94
Rep1-24	459.09	4.15	0.80	2.88
Rep1-25	468.83	4.13	1.03	2.94
Rep1-26	468.01	3.96	0.88	2.94
Rep1-27	421.78	4.01	0.65	2.77
Rep1-28	463.15	4.35	0.78	2.48
Rep1-29	446.11	4.01	0.73	3.05
Rep1-30	450.98	4.63	0.88	3.00
Rep2-1	240.09	13.93	65.33	31.98
Rep2-2	258.75	8.17	64.40	28.64
Rep2-3	322.82	5.48	58.08	23.11
Rep2-4	316.34	5.96	42.71	25.88
Rep2-5	361.76	6.89	47.45	16.02
Rep2-6	277.40	7.01	27.01	13.66
Rep2-7	390.15	5.99	27.21	11.93
Rep2-8	330.94	4.72	14.57	8.76
Rep2-9	401.50	5.99	10.63	6.05
Rep2-10	403.13	5.26	6.34	6.69
Rep2-11	386.90	1.38	4.24	6.45
Rep2-12	419.35	1.33	3.81	6.05
Rep2-13	435.57	1.47	3.11	5.30
Rep2-14	434.76	1.47	2.61	5.13
Rep2-15	440.44	1.44	2.61	4.78
Rep2-16	395.01	1.55	2.33	4.32

Rep2-17	391.77	1.72	2.23	4.32
Rep2-18	408.80	1.70	2.31	4.15
Rep2-19	424.21	1.61	2.36	3.75
Rep2-20	440.44	1.92	1.98	4.09
Rep2-21	446.11	4.27	0.83	3.34
Rep2-22	468.01	4.21	0.75	3.28
Rep2-23	431.51	4.78	0.73	2.94
Rep2-24	476.13	4.58	0.90	3.28
Rep2-25	460.71	4.41	0.73	3.17
Rep2-26	467.20	4.66	0.78	3.23
Rep2-27	493.97	4.80	0.88	3.11
Rep2-28	447.74	4.89	0.88	3.00
Rep2-29	462.34	4.52	0.83	3.23
Rep2-30	467.20	4.63	0.78	3.00
Rep3-1	229.55	25.80	84.71	
Rep3-2	257.94	9.41	85.19	
Rep3-3	253.07	7.37	75.46	
Rep3-4	235.22	8.05	56.75	
Rep3-5	317.96	8.50	54.57	
Rep3-6	322.01	8.08	31.22	
Rep3-7	367.44	8.73	17.40	
Rep3-8	365.81	8.02	10.31	
Rep3-9	292.81	8.87	6.29	
Rep3-10	377.17	9.47	4.71	
Rep3-11	344.72	1.64	6.02	
Rep3-12	322.82	1.78	4.04	
Rep3-13	295.25	1.44	3.49	
Rep3-14	344.72	1.72	2.76	
Rep3-15	335.80	1.95	2.08	
Rep3-16	351.21	1.84	1.96	
Rep3-17	360.14	2.32	1.66	
Rep3-18	407.99	2.20	1.96	
Rep3-19	386.09	2.12	1.76	
Rep3-20	374.74	2.51	2.08	
Rep3-21	417.73	1.30	4.29	
Rep3-22	426.65	0.93	2.43	
Rep3-23	392.58	0.65	2.81	
Rep3-24	408.80	0.99	1.88	
Rep3-25	415.29	0.82	2.01	
Rep3-26	396.64	3.08	2.78	
Rep3-27	397.45	1.02	2.01	
Rep3-28	410.43	1.38	2.26	
Rep3-29	395.82	1.24	1.81	
Rep3-30	411.24	1.75	1.78	
Rep4-1	280.65	11.47	84.86	44.61
Rep4-2	289.57	4.41	67.06	33.60

Rep4-3	289.57	4.10	64.32	21.78
Rep4-4	339.86	4.58	60.06	16.94
Rep4-5	331.75	3.48	51.61	14.00
Rep4-6	373.11	3.62	35.08	10.60
Rep4-7	416.91	3.90	24.12	7.61
Rep4-8	401.50	3.28	11.86	5.82
Rep4-9	453.41	3.73	8.25	5.30
Rep4-10	414.48	3.67	5.34	4.38
Rep4-11	398.26	4.10	4.66	5.53
Rep4-12	390.96	4.18	4.14	4.96
Rep4-13	425.84	4.04	3.01	4.67
Rep4-14	413.67	4.41	3.54	3.98
Rep4-15	399.88	4.32	3.31	3.69
Rep4-16	425.84	4.27	2.86	3.40
Rep4-17	383.66	4.55	2.33	3.17
Rep4-18	341.48	4.83	3.11	2.88
Rep4-19	413.67	4.49	2.96	3.05
Rep4-20	413.67	4.83	2.91	3.17
Rep4-21	355.27	0.14	3.84	6.74
Rep4-22	407.99	0.31	1.45	4.96
Rep4-23	357.70	0.54	1.28	5.71
Rep4-24	378.79	0.73	1.23	4.96
Rep4-25	382.85	0.79	0.98	5.71
Rep4-26	323.64	1.38	0.88	5.42
Rep4-27	401.50	1.41	0.98	5.30
Rep4-28	420.16	1.55	0.63	4.96
Rep4-29	366.62	1.58	0.48	5.53
Rep4-30	436.38	1.78	3.79	5.01
AVG-1	250.03	16.41	81.01	40.42
AVG-2	266.05	7.33	74.66	30.77
AVG-3	288.35	5.91	65.23	24.20
AVG-4	303.76	6.09	54.52	21.75
AVG-5	343.51	6.18	48.49	15.60
AVG-6	340.67	6.16	32.90	12.35
AVG-7	396.23	6.27	23.17	9.85
AVG-8	369.26	5.59	13.28	7.17
AVG-9	393.19	6.37	8.83	5.78
AVG-10	409.41	6.46	6.18	5.82
AVG-11	374.13	2.51	4.75	5.97
AVG-12	383.25	2.52	3.91	5.49
AVG-13	393.80	2.49	3.12	5.05
AVG-14	396.43	2.58	2.79	4.59
AVG-15	400.08	2.64	2.50	4.32
AVG-16	403.94	2.61	2.60	4.01
AVG-17	376.16	2.92	2.05	3.78
AVG-18	400.08	2.83	2.31	3.65

AVG-19	410.83	2.39	2.18	3.46
AVG-20	414.48	2.80	2.30	3.61
AVG-21	423.61	2.38	2.48	4.40
AVG-22	449.16	2.30	1.39	3.75
AVG-23	404.14	2.42	1.37	3.86
AVG-24	430.70	2.61	1.20	3.71
AVG-25	431.92	2.54	1.18	3.94
AVG-26	413.87	3.27	1.33	3.86
AVG-27	428.68	2.81	1.13	3.73
AVG-28	435.37	3.04	1.13	3.48
AVG-29	417.73	2.84	0.96	3.94
AVG-30	441.45	3.20	1.81	3.67

8.4.4. EC 4

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	527.23	17.89	167.99	71.40
Rep1-2	579.95	8.93	129.60	42.70
Rep1-3	680.53	7.57	74.86	34.29
Rep1-4	715.40	7.26	46.42	20.98
Rep1-5	792.46	7.60	19.33	12.33
Rep1-6	837.07	7.43	9.76	10.26
Rep1-7	812.74	7.77	5.84	7.72
Rep1-8	751.09	7.69	5.34	6.86
Rep1-9	844.37	7.60	3.94	6.11
Rep1-10	820.04	7.54	3.86	4.73
Rep1-11	811.12	2.80	3.13	4.38
Rep1-12	814.36	3.02	3.01	4.21
Rep1-13	841.13	2.94	2.68	3.75
Rep1-14	852.48	3.02	3.01	3.52
Rep1-15	780.29	3.05	2.81	2.94
Rep1-16	740.55	3.25	3.01	2.94
Rep1-17	721.89	2.74	2.61	2.88
Rep1-18	850.86	3.25	2.21	2.71
Rep1-19	848.43	3.22	2.68	2.77
Rep1-20	719.46	3.42	2.36	2.77
Rep1-21	851.67	2.29	2.53	3.05
Rep1-22	870.33	1.78	2.11	2.94
Rep1-23	745.42	1.95	2.06	3.00
Rep1-24	546.69	2.03	2.51	2.77
Rep1-25	821.66	2.09	2.06	2.88
Rep1-26	744.61	2.09	1.43	2.82
Rep1-27	694.32	2.12	2.08	2.71
Rep1-28	788.41	2.29	1.93	2.94

Rep1-29	841.94	2.66	2.13	2.77
Rep1-30	790.03	2.54	1.66	2.82
Rep2-1	455.04	20.34	142.51	115.09
Rep2-2	585.63	7.26	99.91	64.43
Rep2-3	668.36	7.32	60.29	34.75
Rep2-4	480.99	6.78	46.29	43.22
Rep2-5	672.42	6.64	16.70	21.84
Rep2-6	785.16	6.30	10.56	10.49
Rep2-7	811.12	6.72	5.69	8.41
Rep2-8	691.88	6.44	3.76	9.62
Rep2-9	870.33	5.93	2.71	6.92
Rep2-10	792.46	6.58	2.48	5.94
Rep2-11	738.93	5.20	3.94	5.13
Rep2-12	811.12	4.83	3.24	4.73
Rep2-13	822.47	5.37	2.83	4.32
Rep2-14	809.49	5.06	3.11	3.80
Rep2-15	859.78	5.23	2.93	3.63
Rep2-16	768.94	5.28	2.96	3.23
Rep2-17	790.03	5.26	3.01	3.17
Rep2-18	828.15	5.54	2.91	3.05
Rep2-19	825.72	5.31	3.13	3.34
Rep2-20	779.48	5.45	2.71	3.11
Rep2-21	829.77	0.68	2.11	3.23
Rep2-22	798.95	1.67	2.28	3.17
Rep2-23	568.59	2.18	2.66	2.82
Rep2-24	842.75	1.61	1.86	3.11
Rep2-25	756.77	2.06	2.36	3.11
Rep2-26	788.41	2.01	2.18	2.94
Rep2-27	816.79	1.22	1.88	2.94
Rep2-28	758.39	1.50	2.23	3.00
Rep2-29	814.36	1.27	0.90	3.11
Rep2-30	736.49	1.24	1.43	3.17
Rep3-1	472.07	29.92	153.15	
Rep3-2	440.44	9.52	105.80	
Rep3-3	592.12	7.83	79.09	
Rep3-4	671.60	6.92	33.35	
Rep3-5	685.39	6.87	11.94	
Rep3-6	635.10	8.00	6.72	
Rep3-7	710.54	7.54	5.39	
Rep3-8	745.42	7.37	4.24	
Rep3-9	783.54	7.91	3.86	
Rep3-10	629.43	8.65	3.86	
Rep3-11	931.97	1.36	3.66	
Rep3-12	921.43	1.30	1.83	
Rep3-13	925.48	1.64	2.01	
Rep3-14	869.52	1.55	1.25	

Rep3-15	721.08	1.92	1.30	
Rep3-16	811.93	1.86	1.20	
Rep3-17	929.54	1.67	1.05	
Rep3-18	870.33	2.23	0.90	
Rep3-19	882.50	1.78	0.75	
Rep3-20	751.91	2.01	0.88	
Rep3-21	567.78	1.75	0.95	
Rep3-22	684.58	1.86	2.21	
Rep3-23	756.77	2.06	1.53	
Rep3-24	819.23	1.89	2.53	
Rep3-25	543.45	2.32	2.81	
Rep3-26	712.16	2.03	2.08	
Rep3-27	644.84	2.15	1.91	
Rep3-28	760.02	2.54	2.26	
Rep3-29	812.74	1.89	0.93	
Rep3-30	741.36	2.12	1.78	
Rep4-1	530.47	19.83	136.27	67.25
Rep4-2	507.76	6.44	98.53	40.63
Rep4-3	720.27	4.44	70.87	29.68
Rep4-4	848.43	4.75	26.63	17.40
Rep4-5	921.43	4.69	9.86	10.60
Rep4-6	856.54	4.78	5.99	7.15
Rep4-7	805.44	4.44	4.09	6.51
Rep4-8	794.89	4.92	3.66	5.07
Rep4-9	938.46	4.83	2.71	4.78
Rep4-10	896.28	4.80	2.53	4.55
Rep4-11	853.29	2.03	1.20	4.32
Rep4-12	807.06	2.06	1.25	4.09
Rep4-13	914.94	1.92	1.15	3.57
Rep4-14	791.65	2.01	1.05	3.57
Rep4-15	893.85	2.23	0.90	2.88
Rep4-16	914.13	2.20	0.83	3.17
Rep4-17	849.24	2.18	0.85	2.65
Rep4-18	855.73	2.20	0.73	2.82
Rep4-19	893.04	2.46	0.85	2.59
Rep4-20	896.28	2.68	0.75	2.54
Rep4-21	736.49	1.84	2.06	6.34
Rep4-22	588.06	1.78	2.03	6.17
Rep4-23	708.10	2.09	1.93	5.59
Rep4-24	760.83	2.26	1.81	6.45
Rep4-25	726.76	2.03	1.76	6.22
Rep4-26	669.17	2.18	1.68	5.53
Rep4-27	745.42	2.20	1.68	5.88
Rep4-28	825.72	2.18	1.68	5.82
Rep4-29	837.88	2.20	1.76	5.99
Rep4-30	752.72	3.02	2.06	6.34

AVG-1	496.20	22.00	149.98	84.58
AVG-2	528.44	8.04	108.46	49.25
AVG-3	665.32	6.79	71.28	32.91
AVG-4	679.11	6.43	38.17	27.20
AVG-5	767.92	6.45	14.46	14.93
AVG-6	778.47	6.63	8.26	9.30
AVG-7	784.96	6.62	5.25	7.55
AVG-8	745.82	6.60	4.25	7.18
AVG-9	859.18	6.57	3.30	5.94
AVG-10	784.55	6.89	3.18	5.07
AVG-11	833.83	2.85	2.98	4.61
AVG-12	838.49	2.80	2.33	4.34
AVG-13	876.01	2.97	2.17	3.88
AVG-14	830.79	2.91	2.11	3.63
AVG-15	813.75	3.11	1.99	3.15
AVG-16	808.89	3.15	2.00	3.11
AVG-17	822.68	2.96	1.88	2.90
AVG-18	851.27	3.31	1.69	2.86
AVG-19	862.42	3.19	1.86	2.90
AVG-20	786.78	3.39	1.67	2.80
AVG-21	746.43	1.64	1.91	4.21
AVG-22	735.48	1.77	2.16	4.09
AVG-23	694.72	2.07	2.04	3.80
AVG-24	742.37	1.95	2.18	4.11
AVG-25	712.16	2.13	2.24	4.07
AVG-26	728.59	2.08	1.84	3.77
AVG-27	725.34	1.92	1.89	3.84
AVG-28	783.13	2.13	2.03	3.92
AVG-29	826.73	2.01	1.43	3.96
AVG-30	755.15	2.23	1.73	4.11

8.4.5. EC 8

Rep#-PV#	*Ca (ppm)*	*Na (ppm)*	*Mg (ppm)*	*K (ppm)*
Rep1-1	1382.95	16.25	243.20	180.55
Rep1-2	894.66	5.23	126.89	140.44
Rep1-3	1711.46	3.28	36.16	44.66
Rep1-4	1610.07	3.62	11.41	24.49
Rep1-5	776.24	3.59	6.19	21.15
Rep1-6	1348.08	3.76	5.22	11.35
Rep1-7	1419.45	3.81	3.76	8.47
Rep1-8	1384.58	4.01	3.39	8.13
Rep1-9	1469.74	4.46	2.11	6.28
Rep1-10	1678.20	4.61	2.56	4.55

Rep1-11	1906.12	5.71	3.61	5.94
Rep1-12	1929.65	5.79	3.06	5.65
Rep1-13	1906.94	5.74	3.46	5.30
Rep1-14	1898.82	6.24	3.29	4.67
Rep1-15	1942.62	5.88	3.13	4.61
Rep1-16	1923.16	6.30	3.21	4.73
Rep1-17	1950.74	6.36	3.08	4.61
Rep1-18	1969.39	6.19	3.21	4.32
Rep1-19	1670.09	7.12	3.41	4.38
Rep1-20	1992.10	6.33	2.96	4.09
Rep1-21	4531.71	0.99	2.21	2.19
Rep1-22	3400.20	1.16	1.63	2.48
Rep1-23	4022.33	0.93	1.58	2.42
Rep1-24	4026.38	1.16	1.10	2.36
Rep1-25	2585.03	0.54	1.25	2.48
Rep1-26	2658.84	1.05	1.03	2.48
Rep1-27	2564.75	0.96	1.00	2.48
Rep1-28	2400.09	0.85	1.25	2.48
Rep1-29	2600.44	0.42	1.00	2.42
Rep1-30	2496.62	0.85	1.18	2.59
Rep2-1	1292.92	26.70	267.70	201.59
Rep2-2	1681.44	8.56	124.83	124.13
Rep2-3	1821.77	8.05	24.98	62.30
Rep2-4	1892.34	7.35	9.98	37.06
Rep2-5	1852.59	7.18	5.34	17.52
Rep2-6	1942.62	8.22	4.56	14.06
Rep2-7	2124.31	8.14	3.74	10.72
Rep2-8	1931.27	8.93	3.89	8.76
Rep2-9	1850.97	8.14	2.31	8.59
Rep2-10	1783.65	8.39	2.76	8.59
Rep2-11	1969.39	3.79	4.79	6.80
Rep2-12	1547.61	3.93	2.56	5.36
Rep2-13	2166.49	3.73	2.41	5.47
Rep2-14	1980.75	3.79	2.13	4.55
Rep2-15	1507.87	3.76	1.86	4.32
Rep2-16	1819.33	3.93	2.13	4.55
Rep2-17	2286.54	4.04	2.03	4.44
Rep2-18	1413.78	4.44	2.18	3.98
Rep2-19	1361.86	4.35	2.01	4.15
Rep2-20	1774.72	4.55	1.86	3.52
Rep2-21	6037.95	1.19	1.18	2.31
Rep2-22	3435.08	1.13	1.30	3.23
Rep2-23	2713.19	1.13	1.40	2.82
Rep2-24	3699.50	0.37	0.95	2.31
Rep2-25	2607.74	0.48	1.35	2.54
Rep2-26	2591.52	0.37	1.50	2.59

Rep2-27	2729.41	0.00	1.35	2.31
Rep2-28	2313.30	0.20	1.43	2.48
Rep2-29	2627.21	0.14	1.50	2.36
Rep2-30	3142.27	0.51	2.48	2.65
Rep3-1	858.16	29.02	259.25	0.00
Rep3-2	1009.84	8.65	154.90	0.00
Rep3-3	1248.31	7.09	41.98	0.00
Rep3-4	1228.03	7.83	15.32	0.00
Rep3-5	1054.45	7.97	8.28	0.00
Rep3-6	1496.51	8.73	5.64	0.00
Rep3-7	1073.11	8.90	4.87	0.00
Rep3-8	1063.37	8.90	4.59	0.00
Rep3-9	1450.28	8.05	4.29	0.00
Rep3-10	1153.41	7.85	4.81	0.00
Rep3-11	1726.06	4.63	4.74	0.00
Rep3-12	1305.90	4.83	2.96	0.00
Rep3-13	1463.25	5.00	1.88	0.00
Rep3-14	1929.65	4.83	1.63	0.00
Rep3-15	1761.75	4.92	2.03	0.00
Rep3-16	1576.00	5.03	1.93	0.00
Rep3-17	2334.39	4.92	2.23	0.00
Rep3-18	2440.65	5.37	1.58	0.00
Rep3-19	1160.71	5.28	2.28	0.00
Rep3-20	2269.50	5.23	2.21	0.00
Rep3-21	1890.71	1.16	3.08	0.00
Rep3-22	1421.89	1.38	2.91	0.00
Rep3-23	1441.35	1.70	2.93	0.00
Rep3-24	1534.63	1.64	2.41	0.00
Rep3-25	1773.10	1.44	2.26	0.00
Rep3-26	1653.06	1.70	2.53	0.00
Rep3-27	1891.52	1.86	2.26	0.00
Rep3-28	1282.38	1.98	2.43	0.00
Rep3-29	1611.69	1.98	2.53	0.00
Rep3-30	1580.06	2.18	3.46	0.00
Rep4-1	1326.18	15.43	230.86	126.61
Rep4-2	1667.66	7.06	140.61	79.53
Rep4-3	1962.09	5.99	43.91	45.99
Rep4-4	1994.54	6.39	12.86	22.07
Rep4-5	1039.04	5.76	6.82	17.29
Rep4-6	1500.57	6.05	4.29	9.80
Rep4-7	1943.44	6.10	3.84	8.30
Rep4-8	1938.57	6.39	3.31	7.15
Rep4-9	1464.07	6.56	3.08	6.80
Rep4-10	1616.56	6.47	2.63	5.47
Rep4-11	1309.95	4.35	4.51	4.26
Rep4-12	1826.63	3.90	3.18	4.55

Rep4-13	1344.83	4.21	2.81	4.15
Rep4-14	1387.82	4.46	2.41	3.80
Rep4-15	882.50	4.49	2.36	4.15
Rep4-16	1551.67	4.52	2.53	4.09
Rep4-17	1615.74	4.58	2.91	4.09
Rep4-18	1089.33	5.23	2.51	3.98
Rep4-19	1206.13	5.40	2.28	3.86
Rep4-20	1369.98	5.31	2.61	3.86
Rep4-21	1434.87	1.75	7.37	1.73
Rep4-22	1366.73	1.86	2.21	1.73
Rep4-23	1336.72	1.78	2.48	1.90
Rep4-24	1361.86	2.03	2.13	1.90
Rep4-25	1008.22	2.35	2.18	2.13
Rep4-26	1401.61	2.35	1.93	2.19
Rep4-27	1514.35	2.09	1.55	2.36
Rep4-28	1134.75	2.37	1.98	2.31
Rep4-29	1361.05	2.63	1.96	2.13
Rep4-30	1424.32	2.74	2.86	2.36
AVG-1	1215.05	21.85	250.25	169.59
AVG-2	1313.40	7.37	136.81	114.70
AVG-3	1685.91	6.10	36.76	50.98
AVG-4	1681.24	6.29	12.39	27.87
AVG-5	1180.58	6.12	6.66	18.65
AVG-6	1571.94	6.69	4.93	11.74
AVG-7	1640.08	6.74	4.05	9.16
AVG-8	1579.45	7.06	3.79	8.01
AVG-9	1558.76	6.80	2.95	7.22
AVG-10	1557.95	6.83	3.19	6.20
AVG-11	1727.88	4.62	4.41	5.67
AVG-12	1652.45	4.61	2.94	5.19
AVG-13	1720.38	4.67	2.64	4.98
AVG-14	1799.26	4.83	2.36	4.34
AVG-15	1523.68	4.76	2.34	4.36
AVG-16	1717.54	4.94	2.45	4.46
AVG-17	2046.85	4.97	2.56	4.38
AVG-18	1728.29	5.30	2.37	4.09
AVG-19	1349.70	5.54	2.50	4.13
AVG-20	1851.58	5.35	2.41	3.82
AVG-21	3473.81	1.27	3.46	2.07
AVG-22	2405.97	1.38	2.01	2.48
AVG-23	2378.40	1.38	2.10	2.38
AVG-24	2655.60	1.30	1.65	2.19
AVG-25	1993.52	1.20	1.76	2.38
AVG-26	2076.26	1.36	1.75	2.42
AVG-27	2175.01	1.23	1.54	2.38
AVG-28	1782.63	1.35	1.77	2.42

AVG-29	2050.10	1.29	1.75	2.31
AVG-30	2160.81	1.57	2.50	2.54

8.5. Appendix E: Black Vertosol Hydraulic Conductivity Data

	Time (h) for PV to flow through				
Rep#-PV#	*EC 0.5*	*EC 1*	*EC 2*	*EC 4*	*EC 8*
Rep1-1	0.378	0.369	0.397	0.494	0.314
Rep1-2	0.336	0.322	0.353	0.453	0.261
Rep1-3	0.356	0.319	0.356	0.469	0.281
Rep1-4	0.417	0.239	0.339	0.422	0.236
Rep1-5	0.367	0.225	0.369	0.364	0.197
Rep1-6	0.469	0.347	0.383	0.467	0.292
Rep1-7	0.403	0.356	0.372	0.461	0.303
Rep1-8	0.414	0.369	0.389	0.469	0.289
Rep1-9	0.386	0.364	0.381	0.519	0.289
Rep1-10	0.383	0.344	0.383	0.472	0.269
Rep2-1	0.389	0.300	0.419	0.425	0.308
Rep2-2	0.336	0.289	0.381	0.367	0.275
Rep2-3	0.328	0.289	0.392	0.319	0.275
Rep2-4	0.314	0.319	0.414	0.328	0.261
Rep2-5	0.336	0.286	0.350	0.264	0.247
Rep2-6	0.306	0.311	0.447	0.350	0.283
Rep2-7	0.361	0.336	0.439	0.372	0.306
Rep2-8	0.364	0.311	0.450	0.369	0.269
Rep2-9	0.353	0.317	0.361	0.383	0.264
Rep2-10	0.300	0.314	0.297	0.356	0.269
Rep3-1	0.372		0.389	0.431	0.325
Rep3-2	0.331		0.281	0.319	0.247
Rep3-3	0.386		0.297	0.333	0.289
Rep3-4	0.411		0.261	0.389	0.269
Rep3-5	0.450		0.311	0.375	0.286
Rep3-6	0.453		0.333	0.353	0.289
Rep3-7	0.453		0.353	0.400	0.306
Rep3-8	0.447		0.361	0.325	0.283
Rep3-9	0.503		0.317	0.383	0.322
Rep3-10	0.486		0.283	0.381	0.294
Rep4-1	0.522	0.369	0.361	0.286	0.297
Rep4-2	0.515	0.325	0.306	0.256	0.253
Rep4-3	0.565	0.331	0.308	0.278	0.274
Rep4-4	0.568	0.338	0.328	0.251	0.249
Rep4-5	0.633	0.340	0.322	0.242	0.256
Rep4-6	0.674	0.357	0.379	0.238	0.264
Rep4-7	0.729	0.376	0.367	0.278	0.261
Rep4-8	0.868	0.401	0.346	0.272	0.275
Rep4-9	0.742	0.368	0.353	0.269	0.282
Rep4-10	0.783	0.383	0.351	0.268	0.276
AVG-1	0.415	0.346	0.392	0.409	0.311

AVG-2	0.380	0.312	0.330	0.349	0.259
AVG-3	0.409	0.313	0.338	0.350	0.280
AVG-4	0.427	0.299	0.335	0.348	0.254
AVG-5	0.447	0.284	0.338	0.311	0.247
AVG-6	0.475	0.338	0.386	0.352	0.282
AVG-7	0.486	0.356	0.383	0.378	0.294
AVG-8	0.523	0.361	0.386	0.359	0.279
AVG-9	0.496	0.350	0.353	0.389	0.289
AVG-10	0.488	0.347	0.329	0.369	0.277

8.6. Appendix F: Red Ferosol Hydraulic Conductivity Data

	Time (h) for PV to flow through				
Rep#-PV#	*EC 0.5*	*EC 1*	*EC 2*	*EC 4*	*EC 8*
Rep1-1	0.044	0.065	0.053	0.053	0.064
Rep1-2	0.044	0.057	0.051	0.047	0.061
Rep1-3	0.047	0.063	0.056	0.046	0.065
Rep1-4	0.051	0.065	0.053	0.047	0.063
Rep1-5	0.046	0.067	0.058	0.051	0.065
Rep1-6	0.050	0.069	0.061	0.058	0.068
Rep1-7	0.050	0.064	0.057	0.061	0.065
Rep1-8	0.050	0.063	0.058	0.064	0.068
Rep1-9	0.049	0.071	0.064	0.064	0.072
Rep1-10	0.051	0.078	0.064	0.058	0.075
Rep2-1	0.060	0.058	0.067	0.060	0.044
Rep2-2	0.063	0.050	0.058	0.053	0.044
Rep2-3	0.058	0.056	0.061	0.056	0.047
Rep2-4	0.061	0.056	0.067	0.060	0.050
Rep2-5	0.064	0.061	0.068	0.075	0.046
Rep2-6	0.065	0.067	0.071	0.065	0.057
Rep2-7	0.060	0.069	0.069	0.065	0.053
Rep2-8	0.065	0.064	0.068	0.067	0.050
Rep2-9	0.065	0.067	0.063	0.067	0.053
Rep2-10	0.069	0.067	0.058	0.067	0.056
Rep3-1	0.083	0.049	0.049	0.050	0.040
Rep3-2	0.092	0.046	0.046	0.044	0.040
Rep3-3	0.092	0.047	0.049	0.046	0.042
Rep3-4	0.097	0.050	0.054	0.046	0.044
Rep3-5	0.100	0.050	0.050	0.047	0.046
Rep3-6	0.103	0.054	0.057	0.054	0.050
Rep3-7	0.106	0.056	0.058	0.050	0.046
Rep3-8	0.106	0.054	0.056	0.051	0.049
Rep3-9	0.114	0.056	0.060	0.050	0.049
Rep3-10	0.113	0.058	0.056	0.053	0.047
Rep4-1	0.072	0.060	0.042	0.061	0.058
Rep4-2	0.069	0.058	0.039	0.057	0.063
Rep4-3	0.079	0.065	0.038	0.060	0.061
Rep4-4	0.078	0.065	0.039	0.067	0.064
Rep4-5	0.090	0.067	0.036	0.065	0.067
Rep4-6	0.083	0.068	0.040	0.075	0.075
Rep4-7	0.081	0.079	0.040	0.076	0.069
Rep4-8	0.082	0.075	0.040	0.069	0.075
Rep4-9	0.086	0.082	0.054	0.081	0.078
Rep4-10	0.092	0.069	0.039	0.076	0.072
AVG-1	0.065	0.058	0.052	0.056	0.052

AVG-2	0.067	0.053	0.049	0.050	0.052
AVG-3	0.069	0.058	0.051	0.052	0.054
AVG-4	0.072	0.059	0.053	0.055	0.055
AVG-5	0.075	0.061	0.053	0.060	0.056
AVG-6	0.075	0.065	0.057	0.063	0.063
AVG-7	0.074	0.067	0.056	0.063	0.058
AVG-8	0.076	0.064	0.056	0.063	0.060
AVG-9	0.078	0.069	0.060	0.065	0.063
AVG-10	0.081	0.068	0.054	0.064	0.063

8.7. Appendix G: Brown Tenosol Hydraulic Conductivity Data

	Time (h) for PV to flow through				
Rep#-PV#	*EC 0.5*	*EC 1*	*EC 2*	*EC 4*	*EC 8*
Rep1-1	0.179	0.125	0.133	0.154	0.150
Rep1-2	0.167	0.113	0.108	0.133	0.129
Rep1-3	0.163	0.113	0.117	0.142	0.133
Rep1-4	0.158	0.113	0.113	0.133	0.133
Rep1-5	0.163	0.113	0.117	0.142	0.133
Rep1-6	0.167	0.113	0.113	0.138	0.143
Rep1-7	0.171	0.117	0.117	0.138	0.136
Rep1-8	0.183	0.117	0.117	0.142	0.133
Rep1-9	0.179	0.113	0.113	0.146	0.133
Rep1-10	0.183	0.113	0.113	0.150	0.133
Rep1-11	0.175	0.113	0.113	0.138	0.138
Rep1-12	0.175	0.117	0.117	0.150	0.133
Rep1-13	0.179	0.121	0.121	0.150	0.142
Rep1-14	0.175	0.121	0.121	0.154	0.142
Rep1-15	0.179	0.121	0.121	0.150	0.138
Rep1-16	0.179	0.129	0.129	0.150	0.133
Rep1-17	0.171	0.125	0.125	0.146	0.133
Rep1-18	0.175	0.121	0.121	0.146	0.138
Rep1-19	0.171	0.125	0.108	0.146	0.175
Rep1-20	0.183	0.125	0.113	0.154	0.138
Rep1-21	0.175	0.117	0.108	0.146	0.142
Rep1-22	0.179	0.121	0.112	0.146	0.138
Rep1-23	0.175	0.125	0.117	0.154	0.138
Rep1-24	0.188	0.125	0.113	0.150	0.142
Rep1-25	0.175	0.121	0.175	0.150	0.154
Rep1-26	0.179	0.129	0.117	0.154	0.138
Rep1-27	0.179	0.113	0.096	0.150	0.138
Rep1-28	0.179	0.129	0.104	0.175	0.142
Rep1-29	0.183	0.121	0.113	0.150	0.142
Rep1-30	0.179	0.125	0.117	0.150	0.142
Rep2-1	0.171	0.150	0.147	0.175	0.283
Rep2-2	0.133	0.133	0.132	0.129	0.263
Rep2-3	0.146	0.133	0.121	0.133	0.258
Rep2-4	0.146	0.129	0.129	0.133	0.254
Rep2-5	0.138	0.129	0.125	0.138	0.250
Rep2-6	0.142	0.138	0.125	0.133	0.238
Rep2-7	0.154	0.138	0.133	0.138	0.254
Rep2-8	0.146	0.146	0.133	0.138	0.246
Rep2-9	0.146	0.146	0.125	0.142	0.242
Rep2-10	0.142	0.146	0.129	0.142	0.242
Rep2-11	0.154	0.142	0.129	0.138	0.246

Rep2-12	0.154	0.142	0.129	0.142	0.229
Rep2-13	0.150	0.146	0.142	0.150	0.238
Rep2-14	0.154	0.142	0.146	0.146	0.242
Rep2-15	0.154	0.142	0.142	0.146	0.242
Rep2-16	0.150	0.138	0.138	0.142	0.250
Rep2-17	0.163	0.138	0.142	0.158	0.250
Rep2-18	0.150	0.142	0.142	0.154	0.225
Rep2-19	0.158	0.142	0.138	0.150	0.242
Rep2-20	0.154	0.142	0.142	0.146	0.238
Rep2-21	0.150	0.142	0.146	0.154	0.242
Rep2-22	0.150	0.142	0.133	0.154	0.258
Rep2-23	0.154	0.150	0.158	0.146	0.246
Rep2-24	0.146	0.142	0.121	0.150	0.233
Rep2-25	0.146	0.138	0.138	0.150	0.250
Rep2-26	0.154	0.129	0.138	0.150	0.258
Rep2-27	0.146	0.138	0.142	0.138	0.242
Rep2-28	0.158	0.138	0.146	0.142	0.250
Rep2-29	0.150	0.142	0.142	0.208	0.233
Rep2-30	0.158	0.142	0.146	0.150	0.258
Rep3-1	0.208	0.221	0.254	0.246	0.221
Rep3-2	0.183	0.188	0.217	0.225	0.200
Rep3-3	0.200	0.192	0.217	0.217	0.192
Rep3-4	0.167	0.188	0.217	0.221	0.200
Rep3-5	0.183	0.188	0.208	0.213	0.200
Rep3-6	0.183	0.179	0.225	0.225	0.208
Rep3-7	0.188	0.188	0.221	0.221	0.204
Rep3-8	0.196	0.188	0.225	0.225	0.204
Rep3-9	0.183	0.192	0.221	0.221	0.200
Rep3-10	0.188	0.188	0.217	0.217	0.200
Rep3-11	0.183	0.188	0.233	0.217	0.204
Rep3-12	0.192	0.183	0.204	0.221	0.204
Rep3-13	0.192	0.188	0.221	0.221	0.204
Rep3-14	0.188	0.188	0.221	0.221	0.204
Rep3-15	0.200	0.183	0.217	0.225	0.196
Rep3-16	0.196	0.183	0.213	0.204	0.204
Rep3-17	0.196	0.192	0.238	0.242	0.221
Rep3-18	0.192	0.192	0.221	0.225	0.204
Rep3-19	0.200	0.192	0.217	0.225	0.208
Rep3-20	0.192	0.183	0.225	0.221	0.208
Rep3-21	0.188	0.183	0.221	0.233	0.208
Rep3-22	0.200	0.192	0.225	0.221	0.208
Rep3-23	0.208	0.200	0.217	0.217	0.213
Rep3-24	0.200	0.192	0.225	0.225	0.204
Rep3-25	0.204	0.188	0.225	0.221	0.208
Rep3-26	0.196	0.196	0.217	0.221	0.204
Rep3-27	0.192	0.188	0.217	0.221	0.208

Rep3-28	0.196	0.187	0.225	0.217	0.200
Rep3-29	0.192	0.196	0.217	0.225	0.208
Rep3-30	0.196	0.192	0.212	0.221	0.208
Rep4-1	0.133	0.229	0.213	0.263	0.163
Rep4-2	0.121	0.196	0.188	0.238	0.138
Rep4-3	0.125	0.200	0.183	0.229	0.142
Rep4-4	0.129	0.192	0.183	0.221	0.138
Rep4-5	0.129	0.188	0.188	0.233	0.133
Rep4-6	0.121	0.196	0.179	0.217	0.138
Rep4-7	0.129	0.204	0.175	0.225	0.138
Rep4-8	0.129	0.200	0.183	0.221	0.154
Rep4-9	0.125	0.200	0.188	0.225	0.154
Rep4-10	0.129	0.196	0.179	0.217	0.142
Rep4-11	0.129	0.192	0.179	0.279	0.146
Rep4-12	0.125	0.200	0.179	0.171	0.138
Rep4-13	0.146	0.196	0.188	0.225	0.133
Rep4-14	0.129	0.196	0.179	0.225	0.138
Rep4-15	0.129	0.188	0.183	0.225	0.133
Rep4-16	0.125	0.179	0.188	0.225	0.138
Rep4-17	0.129	0.196	0.175	0.225	0.138
Rep4-18	0.133	0.192	0.196	0.225	0.142
Rep4-19	0.133	0.196	0.179	0.233	0.142
Rep4-20	0.125	0.196	0.183	0.221	0.142
Rep4-21	0.129	0.192	0.188	0.225	0.154
Rep4-22	0.129	0.208	0.188	0.217	0.142
Rep4-23	0.129	0.196	0.183	0.221	0.142
Rep4-24	0.129	0.208	0.192	0.225	0.138
Rep4-25	0.129	0.192	0.183	0.225	0.146
Rep4-26	0.129	0.192	0.187	0.221	0.150
Rep4-27	0.117	0.196	0.183	0.221	0.138
Rep4-28	0.146	0.196	0.188	0.221	0.138
Rep4-29	0.133	0.188	0.196	0.221	0.138
Rep4-30	0.129	0.196	0.183	0.217	0.137
AVG-1	0.173	0.181	0.187	0.209	0.204
AVG-2	0.151	0.157	0.161	0.181	0.182
AVG-3	0.158	0.159	0.159	0.180	0.181
AVG-4	0.150	0.155	0.160	0.177	0.181
AVG-5	0.153	0.154	0.159	0.181	0.179
AVG-6	0.153	0.156	0.160	0.178	0.182
AVG-7	0.160	0.161	0.161	0.180	0.183
AVG-8	0.164	0.163	0.165	0.181	0.184
AVG-9	0.158	0.163	0.161	0.183	0.182
AVG-10	0.160	0.160	0.159	0.181	0.179
AVG-11	0.160	0.158	0.164	0.193	0.183
AVG-12	0.161	0.160	0.157	0.171	0.176
AVG-13	0.167	0.163	0.168	0.186	0.179

AVG-14	0.161	0.161	0.167	0.186	0.181
AVG-15	0.166	0.158	0.166	0.186	0.177
AVG-16	0.163	0.157	0.167	0.180	0.181
AVG-17	0.165	0.163	0.170	0.193	0.185
AVG-18	0.163	0.161	0.170	0.188	0.177
AVG-19	0.166	0.164	0.160	0.189	0.192
AVG-20	0.164	0.161	0.166	0.185	0.181
AVG-21	0.160	0.158	0.166	0.190	0.186
AVG-22	0.165	0.166	0.165	0.184	0.186
AVG-23	0.167	0.168	0.169	0.184	0.184
AVG-24	0.166	0.167	0.163	0.188	0.179
AVG-25	0.164	0.159	0.180	0.186	0.190
AVG-26	0.165	0.161	0.165	0.186	0.188
AVG-27	0.158	0.158	0.159	0.182	0.181
AVG-28	0.170	0.163	0.166	0.189	0.182
AVG-29	0.165	0.161	0.167	0.201	0.180
AVG-30	0.166	0.164	0.165	0.184	0.186

	Mass of water (g)				
Rep#-PV#	*EC 0.5*	*EC 1*	*EC 2*	*EC 4*	*EC 8*
Rep1-1	148.900	145.906	141.126	139.857	146.123
Rep1-2	142.666	145.700	139.712	140.845	145.872
Rep1-3	140.779	149.984	148.866	148.532	147.503
Rep1-4	140.912	150.536	142.146	142.490	147.295
Rep1-5	142.893	150.500	148.378	145.575	147.954
Rep1-6	142.329	148.328	142.603	143.459	150.087
Rep1-7	145.444	148.689	144.512	140.847	146.263
Rep1-8	148.587	147.125	142.522	141.515	148.489
Rep1-9	144.918	145.831	140.380	150.164	146.531
Rep1-10	144.522	146.852	140.759	149.980	147.717
Rep1-11	142.392	142.764	140.541	141.780	147.124
Rep1-12	142.312	146.270	138.462	145.919	149.536
Rep1-13	145.227	142.977	139.958	142.007	150.717
Rep1-14	146.796	143.069	141.156	144.945	147.242
Rep1-15	144.115	143.708	146.832	144.051	146.800
Rep1-16	147.141	153.738	146.800	142.744	146.595
Rep1-17	141.532	146.428	160.142	140.797	145.839
Rep1-18	143.761	151.156	167.027	142.610	146.908
Rep1-19	142.938	142.685	151.502	141.111	146.226
Rep1-20	151.351	142.947	149.430	144.723	153.063
Rep1-21	143.141	138.514	149.175	140.810	144.171
Rep1-22	147.960	144.033	157.691	140.660	144.674
Rep1-23	144.541	142.884	140.833	149.637	143.416
Rep1-24	146.560	145.630	145.201	145.521	148.974
Rep1-25	146.331	139.900	147.946	142.222	161.959

Rep1-26	144.532	142.246	145.975	141.858	146.549
Rep1-27	148.978	147.626	161.788	142.985	146.939
Rep1-28	146.454	149.049	147.390	152.218	145.401
Rep1-29	149.957	151.454	143.854	145.642	148.249
Rep1-30	144.159	148.490	148.319	145.986	149.024
Rep2-1	152.224	146.396	154.237	164.611	145.021
Rep2-2	138.478	147.261	159.880	141.479	146.197
Rep2-3	150.465	145.993	144.408	145.020	148.067
Rep2-4	147.373	143.429	145.744	150.109	144.813
Rep2-5	140.949	145.338	143.818	144.697	146.303
Rep2-6	144.863	142.493	145.099	143.677	144.863
Rep2-7	151.678	141.708	151.183	145.420	146.984
Rep2-8	147.962	145.065	143.534	147.877	144.658
Rep2-9	145.347	149.693	145.593	150.653	143.294
Rep2-10	144.235	144.491	142.100	149.315	144.351
Rep2-11	145.520	143.622	143.573	143.349	143.405
Rep2-12	148.426	147.195	145.339	146.158	140.269
Rep2-13	139.844	148.077	146.937	148.091	139.590
Rep2-14	143.097	149.247	152.269	145.730	145.255
Rep2-15	145.625	144.008	144.955	144.543	143.613
Rep2-16	153.342	140.775	145.493	140.736	148.310
Rep2-17	149.263	146.266	144.883	158.574	143.085
Rep2-18	145.490	142.564	145.539	143.612	144.558
Rep2-19	148.536	145.172	144.432	144.924	147.380
Rep2-20	150.186	142.943	149.278	144.544	146.352
Rep2-21	145.096	144.786	147.755	147.915	144.070
Rep2-22	146.876	145.847	140.119	153.175	154.431
Rep2-23	148.864	151.369	149.823	148.371	148.033
Rep2-24	145.121	145.120	143.220	142.710	149.590
Rep2-25	147.122	145.234	144.053	146.687	149.708
Rep2-26	158.427	143.058	148.396	147.941	143.592
Rep2-27	152.103	143.419	145.730	142.881	152.259
Rep2-28	150.611	152.997	153.695	146.213	145.934
Rep2-29	148.249	143.945	141.592	151.774	143.625
Rep2-30	149.500	147.244	149.485	140.874	145.433
Rep3-1	143.968	142.966	141.319	140.020	139.841
Rep3-2	147.380	143.840	141.594	144.366	142.216
Rep3-3	143.590	144.722	143.981	140.717	141.198
Rep3-4	145.933	143.602	142.980	141.595	145.273
Rep3-5	141.513	143.088	140.963	139.451	144.873
Rep3-6	144.188	140.992	148.346	144.808	149.787
Rep3-7	146.046	144.755	145.952	141.212	144.937
Rep3-8	148.245	145.720	149.044	144.968	144.370
Rep3-9	141.751	150.103	147.989	140.246	145.038
Rep3-10	143.746	145.668	142.461	139.462	143.868
Rep3-11	143.700	146.380	142.754	143.433	147.022

Rep3-12	143.442	142.033	142.143	138.543	142.693
Rep3-13	142.503	143.484	144.783	141.195	142.671
Rep3-14	144.680	144.075	143.596	141.323	144.612
Rep3-15	146.823	141.491	144.001	143.560	140.683
Rep3-16	151.657	145.172	154.583	146.860	144.900
Rep3-17	144.801	144.139	145.330	144.489	154.335
Rep3-18	144.296	149.235	145.199	142.478	146.671
Rep3-19	146.702	145.352	145.911	144.907	145.105
Rep3-20	144.127	141.945	147.986	144.355	147.714
Rep3-21	144.673	143.250	145.733	149.821	146.234
Rep3-22	151.694	146.293	148.018	144.525	145.841
Rep3-23	155.294	152.264	143.137	140.911	149.272
Rep3-24	148.453	146.037	148.200	142.232	142.715
Rep3-25	155.410	146.299	150.283	143.065	147.157
Rep3-26	146.852	152.130	142.445	141.566	143.875
Rep3-27	143.694	145.386	145.529	144.893	144.105
Rep3-28	143.191	144.427	146.898	146.667	141.644
Rep3-29	142.239	153.670	145.548	143.268	148.860
Rep3-30	144.842	148.747	145.022	142.865	146.742
Rep4-1	143.373	144.734	148.353	145.873	145.431
Rep4-2	143.771	142.013	146.876	150.606	145.908
Rep4-3	145.625	146.996	148.713	144.596	149.746
Rep4-4	148.372	143.942	145.481	142.164	148.239
Rep4-5	148.892	145.571	146.881	147.857	145.997
Rep4-6	142.976	145.238	143.910	139.528	146.332
Rep4-7	146.103	150.766	141.875	143.995	144.086
Rep4-8	145.516	148.206	143.531	140.787	161.053
Rep4-9	145.509	150.990	152.061	142.923	165.242
Rep4-10	148.538	146.607	141.938	140.693	147.617
Rep4-11	146.792	143.558	142.884	147.578	150.874
Rep4-12	144.614	146.942	142.594	143.098	148.270
Rep4-13	167.339	145.752	147.216	144.115	143.129
Rep4-14	144.144	147.706	145.445	142.707	147.619
Rep4-15	149.847	140.948	142.218	144.224	141.875
Rep4-16	143.315	142.876	147.901	143.783	144.961
Rep4-17	147.110	143.991	142.786	144.316	145.062
Rep4-18	153.785	146.836	146.502	143.270	148.554
Rep4-19	152.966	145.452	142.723	153.037	152.251
Rep4-20	144.803	145.669	141.300	141.405	151.155
Rep4-21	147.521	146.006	145.126	148.194	165.454
Rep4-22	147.006	154.025	142.698	141.724	144.571
Rep4-23	145.393	144.611	140.478	142.538	150.835
Rep4-24	142.775	156.728	149.636	147.011	141.952
Rep4-25	154.611	143.025	141.841	146.457	157.021
Rep4-26	146.161	142.449	148.018	142.542	156.412
Rep4-27	153.071	146.962	139.292	144.408	145.658

Rep4-28	147.054	145.678	145.276	145.002	144.776
Rep4-29	147.641	143.028	150.615	144.739	148.680
Rep4-30	151.524	143.952	140.318	140.711	143.766
AVG-1	147.116	145.001	146.259	147.590	144.104
AVG-2	143.074	144.704	147.016	144.324	145.048
AVG-3	145.115	146.924	146.492	144.716	146.629
AVG-4	145.648	145.377	144.088	144.090	146.405
AVG-5	143.562	146.124	145.010	144.395	146.282
AVG-6	143.589	144.263	144.990	142.868	147.767
AVG-7	147.318	146.480	145.881	142.869	145.568
AVG-8	147.578	146.529	144.658	143.787	149.643
AVG-9	144.381	149.154	146.506	145.997	150.026
AVG-10	145.260	145.905	141.815	144.863	145.888
AVG-11	144.601	144.081	142.438	144.035	147.106
AVG-12	144.699	145.610	142.135	143.430	145.192
AVG-13	148.728	145.073	144.724	143.852	144.027
AVG-14	144.679	146.024	145.617	143.676	146.182
AVG-15	146.603	142.539	144.502	144.095	143.243
AVG-16	148.864	145.640	148.694	143.531	146.192
AVG-17	145.677	145.206	148.285	147.044	147.080
AVG-18	146.833	147.448	151.067	142.993	146.673
AVG-19	147.786	144.665	146.142	145.995	147.741
AVG-20	147.617	143.376	146.999	143.757	149.571
AVG-21	145.108	143.139	146.947	146.685	149.982
AVG-22	148.384	147.550	147.132	145.021	147.379
AVG-23	148.523	147.782	143.568	145.364	147.889
AVG-24	145.727	148.379	146.564	144.369	145.808
AVG-25	150.869	143.615	146.031	144.608	153.961
AVG-26	148.993	144.971	146.209	143.477	147.607
AVG-27	149.462	145.848	148.085	143.792	147.240
AVG-28	146.828	148.038	148.315	147.525	144.439
AVG-29	147.022	148.024	145.402	146.356	147.354
AVG-30	147.506	147.108	145.786	142.609	146.241

8.8. Appendix H: Black Vertosol Electrical Conductivity Data

	Electrical Conductivity (dS/m)				
Rep#-PV#	*EC 0.5*	*EC 1*	*EC 2*	*EC 4*	*EC 8*
Rep1-1	1.009	1.606	2.506	4.24	7.59
Rep1-2	0.57	1.096	1.979	3.71	6.81
Rep1-3	0.542	1.052	1.931	3.6	6.78
Rep1-4	0.539	1.052	1.938	3.6	6.78
Rep1-5	0.547	1.052	1.915	3.66	6.74
Rep1-6	0.532	1.052	1.936	3.58	6.71
Rep1-7	0.525	1.035	1.908	3.57	6.71
Rep1-8	0.531	1.035	1.925	3.56	6.73
Rep1-9	0.531	1.037	1.927	3.58	6.75
Rep1-10	0.527	1.043	1.932	3.58	6.78
Rep2-1	1.118	1.602	2.585	4.34	7.54
Rep2-2	0.589	1.077	1.984	3.64	6.9
Rep2-3	0.542	1.035	1.936	3.59	6.79
Rep2-4	0.541	1.035	1.93	3.58	6.9
Rep2-5	0.533	1.019	1.943	3.58	6.76
Rep2-6	0.526	1.025	1.921	3.6	6.75
Rep2-7	0.533	1.015	1.927	3.56	6.73
Rep2-8	0.525	1.02	1.911	3.56	6.8
Rep2-9	0.525	1.024	1.924	3.55	6.82
Rep2-10	0.525	1.022	1.94	3.57	6.8
Rep3-1	1.073	0	2.584	4.29	7.48
Rep3-2	0.584	0	1.983	3.66	6.76
Rep3-3	0.555	0	1.94	3.6	6.68
Rep3-4	0.552	0	1.933	3.63	6.68
Rep3-5	0.547	0	1.926	3.57	6.59
Rep3-6	0.536	0	1.916	3.58	6.53
Rep3-7	0.53	0	1.924	3.56	6.52
Rep3-8	0.533	0	1.917	3.58	6.56
Rep3-9	0.531	0	1.943	3.56	6.54
Rep3-10	0.531	0	1.943	3.56	6.53
Rep4-1	1.091	1.594	2.538	4.15	7.44
Rep4-2	0.587	1.083	1.992	3.69	6.83
Rep4-3	0.542	1.038	1.933	3.64	6.75
Rep4-4	0.546	1.029	1.933	3.56	6.73
Rep4-5	0.523	1.029	1.917	3.52	6.84
Rep4-6	0.507	1.029	1.918	3.6	6.65
Rep4-7	0.53	1.027	1.911	3.57	6.74
Rep4-8	0.521	1.022	1.908	3.57	6.75
Rep4-9	0.526	1.027	1.914	3.56	6.7
Rep4-10	0.523	1.027	1.916	3.56	6.77
AVG-1	1.073	1.601	2.553	4.255	7.513

AVG-2	0.583	1.085	1.985	3.675	6.825
AVG-3	0.545	1.042	1.935	3.608	6.750
AVG-4	0.545	1.039	1.934	3.593	6.773
AVG-5	0.538	1.033	1.925	3.583	6.733
AVG-6	0.525	1.035	1.923	3.590	6.660
AVG-7	0.530	1.026	1.918	3.565	6.675
AVG-8	0.528	1.026	1.915	3.568	6.710
AVG-9	0.528	1.029	1.927	3.563	6.703
AVG-10	0.527	1.031	1.933	3.568	6.720

8.9. Appendix I: Red Ferosol Electrical Conductivity Data

	Electrical Conductivity (dS/m)				
Rep#-PV#	*EC 0.5*	*EC 1*	*EC 2*	*EC 4*	*EC 8*
Rep1-1	0.63	1.315	2.354	4.31	8.11
Rep1-2	0.601	1.289	2.33	4.25	8.21
Rep1-3	0.581	1.27	2.296	4.3	8.07
Rep1-4	0.565	1.254	2.302	4.3	8.19
Rep1-5	0.562	1.243	2.299	4.3	8.25
Rep1-6	0.552	1.232	2.291	4.32	8.25
Rep1-7	0.555	1.228	2.281	4.29	8.28
Rep1-8	0.547	1.195	2.281	4.3	8.28
Rep1-9	0.553	1.223	2.276	4.3	8.28
Rep1-10	0.541	1.22	2.277	4.28	8.2
Rep2-1	0.626	1.121	2.344	4.3	8.19
Rep2-2	0.608	1.105	2.327	4.3	8.1
Rep2-3	0.596	1.097	2.297	4.24	8.23
Rep2-4	0.571	1.082	2.289	4.085	8.2
Rep2-5	0.561	1.082	2.31	4.29	8.23
Rep2-6	0.553	1.052	2.31	4.3	8.21
Rep2-7	0.547	1.048	2.295	4.31	8.24
Rep2-8	0.542	1.056	2.252	4.24	8.28
Rep2-9	0.54	1.054	2.289	4.28	8.26
Rep2-10	0.539	1.052	2.291	4.29	8.13
Rep3-1	0.776	1.343	2.378	4.31	8.17
Rep3-2	0.718	1.289	2.306	4.28	8.2
Rep3-3	0.701	1.274	2.293	4.27	8.22
Rep3-4	0.678	1.253	2.309	4.31	8.25
Rep3-5	0.661	1.238	2.273	4.28	8.25
Rep3-6	0.647	1.228	2.276	4.31	8.24
Rep3-7	0.644	1.4	2.269	4.28	8.28
Rep3-8	0.638	1.223	2.274	4.4	8.24
Rep3-9	0.634	1.214	2.278	4.31	8.24
Rep3-10	0.632	1.214	2.273	4.31	8.28
Rep4-1	0.727	1.35	2.316	4.27	8.16
Rep4-2	0.695	1.286	2.276	4.3	8.2
Rep4-3	0.685	1.262	2.287	4.24	8.04
Rep4-4	0.671	1.258	2.276	4.3	8.21
Rep4-5	0.667	1.243	2.347	4.28	8.14
Rep4-6	0.644	1.249	2.296	4.21	8.25
Rep4-7	0.637	1.226	2.27	4.27	8.12
Rep4-8	0.633	1.229	2.289	4.22	8.19
Rep4-9	0.634	1.226	2.239	4.27	8.26
Rep4-10	0.632	1.219	2.266	4.25	8.13
AVG-1	0.690	1.282	2.348	4.298	8.158

AVG-2	0.656	1.242	2.310	4.283	8.178
AVG-3	0.641	1.226	2.293	4.263	8.140
AVG-4	0.621	1.212	2.294	4.249	8.213
AVG-5	0.613	1.202	2.307	4.288	8.218
AVG-6	0.599	1.190	2.293	4.285	8.238
AVG-7	0.596	1.226	2.279	4.288	8.230
AVG-8	0.590	1.176	2.274	4.290	8.248
AVG-9	0.590	1.179	2.271	4.290	8.260
AVG-10	0.586	1.176	2.277	4.283	8.185

8.10. Appendix J: Brown Tenosol Electrical Conductivity Data

	Electrical Conductivity (dS/m)				
Rep#-PV#	*EC 0.5*	*EC 1*	*EC 2*	*EC 4*	*EC 8*
Rep1-1	0.729	1.285	2.160	3.850	7.090
Rep1-2	0.571	1.109	2.044	3.770	7.140
Rep1-3	0.562	1.096	2.038	3.760	7.110
Rep1-4	0.558	1.088	2.022	3.740	7.090
Rep1-5	0.556	1.081	2.014	3.730	7.080
Rep1-6	0.557	1.078	2.004	3.730	7.070
Rep1-7	0.565	1.074	2.002	3.720	7.090
Rep1-8	0.581	1.071	2.012	3.720	7.090
Rep1-9	0.579	1.062	2.002	3.720	7.070
Rep1-10	0.573	1.061	1.998	3.710	7.050
Rep1-11	0.570	1.059	2.001	3.710	7.040
Rep1-12	0.569	1.056	2.001	3.710	7.040
Rep1-13	0.567	1.054	2.012	3.760	7.030
Rep1-14	0.567	1.052	2.012	3.810	7.050
Rep1-15	0.566	1.054	2.020	3.810	7.070
Rep1-16	0.571	1.061	2.027	3.830	7.100
Rep1-17	0.565	1.054	2.018	3.820	7.050
Rep1-18	0.564	1.050	2.020	3.800	7.040
Rep1-19	0.563	1.050	2.023	3.820	7.050
Rep1-20	0.571	1.054	2.026	3.810	7.030
Rep1-21	0.562	1.049	2.014	3.800	7.030
Rep1-22	0.563	1.052	2.024	3.810	7.040
Rep1-23	0.565	1.054	2.022	3.830	7.070
Rep1-24	0.566	1.054	2.033	3.830	7.090
Rep1-25	0.565	1.054	2.027	3.820	7.040
Rep1-26	0.567	1.054	2.024	3.820	7.070
Rep1-27	0.572	1.054	2.346	3.830	7.070
Rep1-28	0.569	1.058	2.039	3.850	7.070
Rep1-29	0.576	1.060	2.053	3.850	7.130
Rep1-30	0.584	1.062	2.066	3.900	7.260
Rep2-1	0.721	1.271	2.164	3.820	7.190
Rep2-2	0.571	1.095	2.041	3.750	7.250
Rep2-3	0.561	1.085	2.028	3.740	7.200
Rep2-4	0.559	1.081	2.020	3.720	7.170
Rep2-5	0.555	1.075	2.009	3.710	7.160
Rep2-6	0.554	1.075	2.004	3.710	7.160
Rep2-7	0.554	1.067	2.001	3.710	7.180
Rep2-8	0.556	1.070	2.020	3.740	7.230
Rep2-9	0.549	1.057	1.998	3.710	7.170
Rep2-10	0.546	1.052	1.990	3.710	7.110
Rep2-11	0.544	1.052	1.988	3.690	7.110

Rep2-12	0.554	1.052	1.996	3.690	7.100
Rep2-13	0.563	1.050	2.007	3.740	7.090
Rep2-14	0.563	1.048	2.007	3.770	7.090
Rep2-15	0.563	1.049	2.009	3.770	7.110
Rep2-16	0.564	1.056	2.031	3.820	7.190
Rep2-17	0.566	1.053	2.019	3.790	7.150
Rep2-18	0.562	1.048	2.009	3.770	7.110
Rep2-19	0.561	1.048	2.007	3.770	7.090
Rep2-20	0.562	1.048	2.006	3.770	7.090
Rep2-21	0.560	1.046	2.003	3.760	7.090
Rep2-22	0.562	1.046	2.008	3.770	7.100
Rep2-23	0.562	1.052	2.015	3.820	7.160
Rep2-24	0.554	1.058	2.029	3.830	7.190
Rep2-25	0.541	1.056	2.016	3.820	7.170
Rep2-26	0.535	1.053	2.011	3.810	7.140
Rep2-27	0.535	1.052	2.011	3.780	7.110
Rep2-28	0.533	1.050	2.011	3.770	7.120
Rep2-29	0.539	1.050	2.019	3.770	7.120
Rep2-30	0.558	1.061	2.014	3.780	7.140
Rep3-1	0.847	1.323	2.238	4.030	7.310
Rep3-2	0.618	1.109	2.072	3.870	7.220
Rep3-3	0.601	1.091	2.053	3.850	7.210
Rep3-4	0.592	1.082	2.039	3.830	7.170
Rep3-5	0.587	1.077	2.027	3.820	7.160
Rep3-6	0.584	1.074	2.025	3.810	7.160
Rep3-7	0.583	1.067	2.024	3.820	7.180
Rep3-8	0.592	1.067	2.042	3.850	7.220
Rep3-9	0.581	1.064	2.028	3.820	7.160
Rep3-10	0.574	1.052	2.014	3.780	7.120
Rep3-11	0.570	1.049	2.009	3.780	7.110
Rep3-12	0.567	1.050	2.007	3.770	7.090
Rep3-13	0.564	1.050	2.006	3.780	7.080
Rep3-14	0.563	1.047	2.003	3.770	7.070
Rep3-15	0.564	1.048	2.004	3.780	7.090
Rep3-16	0.566	1.056	2.024	3.840	7.140
Rep3-17	0.565	1.056	2.018	3.820	7.190
Rep3-18	0.561	1.048	2.007	3.770	7.100
Rep3-19	0.562	1.046	2.006	3.770	7.070
Rep3-20	0.560	1.046	2.007	3.760	7.090
Rep3-21	0.557	1.046	2.003	3.760	7.070
Rep3-22	0.560	1.046	2.009	3.760	7.090
Rep3-23	0.564	1.084	2.012	3.820	7.130
Rep3-24	0.569	1.056	2.030	3.840	7.180
Rep3-25	0.564	1.054	2.015	3.810	7.150
Rep3-26	0.565	1.067	2.009	3.800	7.110
Rep3-27	0.563	1.049	2.009	3.780	7.110

Rep3-28	0.562	1.049	2.007	3.770	7.110
Rep3-29	0.563	1.065	2.007	3.770	7.110
Rep3-30	0.572	1.061	2.023	3.780	7.150
Rep4-1	0.845	1.314	2.232	4.030	7.320
Rep4-2	0.615	1.111	2.072	3.870	7.220
Rep4-3	0.599	1.092	2.058	3.850	7.190
Rep4-4	0.597	1.083	2.041	3.820	7.170
Rep4-5	0.589	1.077	2.031	3.820	7.160
Rep4-6	0.589	1.071	2.026	3.810	7.150
Rep4-7	0.587	1.073	2.020	3.820	7.170
Rep4-8	0.587	1.066	2.036	3.840	7.220
Rep4-9	0.578	1.073	2.026	3.830	7.170
Rep4-10	0.571	1.050	2.013	3.780	7.130
Rep4-11	0.567	1.050	2.012	3.780	7.140
Rep4-12	0.565	1.050	2.013	3.760	7.110
Rep4-13	0.561	1.054	2.011	3.770	7.090
Rep4-14	0.562	1.048	2.006	3.770	7.090
Rep4-15	0.562	1.050	2.007	3.770	7.110
Rep4-16	0.564	1.061	2.028	3.830	7.190
Rep4-17	0.565	1.056	2.020	3.830	7.170
Rep4-18	0.562	1.055	2.011	3.780	7.110
Rep4-19	0.558	1.049	2.003	3.770	7.090
Rep4-20	0.558	1.054	2.001	3.770	7.110
Rep4-21	0.560	1.053	2.001	3.760	7.090
Rep4-22	0.560	1.052	2.003	3.770	7.090
Rep4-23	0.562	1.052	2.006	3.770	7.130
Rep4-24	0.565	1.065	2.030	3.830	7.190
Rep4-25	0.564	1.054	2.018	3.820	7.170
Rep4-26	0.562	1.052	2.011	3.780	7.140
Rep4-27	0.562	1.049	2.006	3.770	7.120
Rep4-28	0.560	1.048	2.006	3.760	7.120
Rep4-29	0.562	1.050	2.004	3.760	7.120
Rep4-30	0.565	1.057	2.012	3.770	7.160
AVG-1	0.786	1.298	2.199	3.933	7.228
AVG-2	0.594	1.106	2.057	3.815	7.208
AVG-3	0.581	1.091	2.044	3.800	7.178
AVG-4	0.577	1.084	2.031	3.778	7.150
AVG-5	0.572	1.078	2.020	3.770	7.140
AVG-6	0.571	1.075	2.015	3.765	7.135
AVG-7	0.572	1.070	2.012	3.768	7.155
AVG-8	0.579	1.069	2.028	3.788	7.190
AVG-9	0.572	1.064	2.014	3.770	7.143
AVG-10	0.566	1.054	2.004	3.745	7.103
AVG-11	0.563	1.053	2.003	3.740	7.100
AVG-12	0.564	1.052	2.004	3.733	7.085
AVG-13	0.564	1.052	2.009	3.763	7.073

AVG-14	0.564	1.049	2.007	3.780	7.075
AVG-15	0.564	1.050	2.010	3.783	7.095
AVG-16	0.566	1.059	2.028	3.830	7.155
AVG-17	0.565	1.055	2.019	3.815	7.140
AVG-18	0.562	1.050	2.012	3.780	7.090
AVG-19	0.561	1.048	2.010	3.783	7.075
AVG-20	0.563	1.051	2.010	3.778	7.080
AVG-21	0.560	1.049	2.005	3.770	7.070
AVG-22	0.561	1.049	2.011	3.778	7.080
AVG-23	0.563	1.061	2.014	3.810	7.123
AVG-24	0.564	1.058	2.031	3.833	7.163
AVG-25	0.559	1.055	2.019	3.818	7.133
AVG-26	0.557	1.057	2.014	3.803	7.115
AVG-27	0.558	1.051	2.093	3.790	7.103
AVG-28	0.556	1.051	2.016	3.788	7.105
AVG-29	0.560	1.056	2.021	3.788	7.120
AVG-30	0.570	1.060	2.029	3.808	7.178

8.11. Appendix K: Tukey’s Honest Significant Difference (HSD) Values ($\alpha = 0.05$)

8.11.1. Black Vertosol

PV	*Na*	*Mg*	*K*
1	21.828	3.416	2.514
2	36.030	4.667	4.551
3	40.478	4.831	7.280
4	41.721	8.568	8.984
5	43.657	15.793	12.628
6	42.983	15.576	14.324
7	42.643	16.501	16.865
8	43.265	16.937	17.886
9	43.545	17.640	20.113
10	43.209	23.543	21.884

EC	*Na*	*Mg*	*K*
0.5	1.026	0.266	0.168
1	0.601	0.268	0.152
2	0.478	0.212	0.168
4	1.660	0.059	1.404
8	0.715	0.033	1.645

8.11.2. Red Ferosol

PV	*Na*	*Mg*	*K*
1	2.767	13.205	1.691
2	4.366	24.734	2.588
3	5.898	29.843	3.383
4	6.797	33.952	3.822
5	7.687	38.274	4.488
6	8.727	41.458	5.225
7	9.437	46.831	5.679
8	10.301	50.549	6.579
9	10.795	49.677	7.440
10	11.136	50.177	7.848

EC	*Na*	*Mg*	*K*

0.5	6.819	1.794	0.050
1	4.009	3.371	0.153
2	11.193	5.097	0.246
4	5.419	4.191	0.129
8	9.463	8.212	0.526

8.11.3. Brown Tenosol

PV	*Na*	*Mg*	*K*
1		8.287	2.083
2		13.362	3.086
3		15.723	2.981
4		18.529	3.407
5		20.081	3.432
6		21.200	3.412
7		21.298	3.427
8		21.971	3.478
9		22.254	3.478
10		22.899	3.538
11		23.260	3.673
12		23.615	3.819
13		23.615	3.949
14		23.790	4.045
15		23.878	4.130
16		23.703	4.220
17		23.703	4.291
18		23.790	4.346
19		23.965	4.426
20		24.138	4.486
21		24.224	4.361
22		24.224	4.270
23		24.309	4.045
24		24.395	3.939
25		24.480	3.859
26		24.565	3.794
27		24.649	3.718
28		24.734	3.668
29		24.901	3.613
30		24.985	3.558