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## **Assessment via discriminant analysis of soil suitability for effluent renovation using undisturbed soil columns.**

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### **Abstract**

The use of onsite wastewater treatment systems for the treatment and disposal of effluent is common in urban fringe areas which are not serviced by centralised wastewater collection systems. However, due to inappropriate siting and soil characteristics, the inherent failure of these systems, in particular subsurface soil treatment systems, are numerous. In order to ensure that these systems are capable of providing adequate treatment and disposal of effluent in the long term, it is essential that the soils' ability to both renovate as well as dispose of discharged effluent is adequately assessed. This paper discusses the outcomes of a research study undertaken through the use of undisturbed soil columns, to assess the ability different soil types to treat and dispose of primary treated effluent. Discriminant Analysis (DA) was utilised for classification of the various soil types based on their respective physical and chemical characteristics and to identify relative changes in each soil type after an extended period of application of effluent. Ferrosol and Dermosol soils were found to provide the most satisfactory conditions for effluent renovation. Kurosol, Sodosl and Chromosol soils even though were found to provide suitable means for removing effluent pollutants, reductions in the soils' permeability over time indicated that these soils may not be appropriate for long term effluent treatment. Finally,

Podosol soils were found to have minimal ability to provide adequate treatment of effluent.

Keywords: Onsite wastewater treatment, soil columns, effluent renovation, Discriminant Analysis

## **Introduction**

The onsite treatment and disposal of wastewater is the most feasible option in urban fringe areas which are not serviced by reticulated wastewater collection systems. The use of these systems for the treatment and disposal of wastewater is dependant on a range of soil and site related factors ([Dawes and Goonetilleke 2003](#), [Whitehead and Geary 2000](#)). Soil plays a major role in the attenuation and removal of different pollutants contained in the effluent. This is because common onsite wastewater treatment systems such as septic tanks are designed to treat sewage only partially and there is an explicit dependency on soil systems for final treatment and appropriate disposal. Unfortunately, not all soil types have the capacity to provide adequate treatment and disposal of sewage effluent. The ability of soil to provide adequate treatment is particularly important in the case of septic tank-subsurface effluent disposal systems which is by far the most common system adopted in practice. A typical septic tank soil adsorption systems is depicted in [Figure 1](#). The failure of onsite systems is common and is cause for concern as the release of poorly treated effluent into the surrounding environment can substantially increase environmental and public health risks. Studies undertaken in Australia have noted a general failure rate of over 70% ([Goonetilleke et al 2000](#), [Goonetilleke et al 2002](#), [Whitehead and Geary 2000](#), [Martens and Geary 1999](#), [Martens and Warner 1995](#)). Similarly, in the USA septic tank failure rates of up to 72% have been reported ([USEPA 1997](#)).

To be able to adequately treat and dispose of discharged effluent, the soil must have sufficient permeability and drainage characteristics to allow the effluent to infiltrate through the soil matrix. This allows further chemical processes to take place in order to remove pollutants such as nutrients. The soil must also contain sufficient ion exchange properties to permit the adsorption of effluent constituents. Cation Exchange Capacity, or CEC, is one property which provides an indication of the ionic

charge of the soil and therefore acts as a measure for evaluating its ability for effluent renovation (Khalil et al 2004, Dawes and Goonetilleke 2003). The CEC of a soil is influenced by a number of factors. Organic matter (%OM) for example, retains very high ionic forces which can increase a soil's ionic exchange capacity (Oorts et al 2003). However, large amounts of organic matter can also cause water repellence, and therefore reduce infiltration (Ferreira et al 2000). Similarly, both the amount and type of clay present in the soil also has an impact on the CEC, as well as the permeability of a soil. Clays that has smectite mineralogy generally have higher CEC levels compared to soils with other clay mineralogy such as kaolinite or illite (Coppin et al 2002, Khalil et al 2004). However, smectite is also a high-shrink swell clay, which can impede water infiltration, particularly if a high percentage is present in the soil (Miranda-Trevino and Coles 2003, Di Maio et al 2004)).

Individual cations, such as magnesium (Mg), calcium (Ca) and sodium (Na) can also influence the renovation and infiltration of effluent through a soil. Although providing numerous cation exchange sites for adsorbing effluent pollutants, high concentrations of cations such as Na and Mg, can cause dispersion of the clay particles and effectively impede water flow through the soil (Dawes and Goonetilleke 2003, Prasad et al 2001). This is of particular significance to onsite systems as high levels of Na are typically found in effluent from the use of washing powders and cleaners. Additionally it can also increase over time the levels of sodium ions in the soil. Therefore, in order to adequately assess a soil's long-term ability to renovate effluent including its ability to attenuate effluent pollutants and provide sufficient disposal capability, permeability and drainage characteristics, as well as the physico-chemical characteristics, such as CEC and %OM need to be investigated.

A suitability ranking based on soil renovation ability was developed by Carroll et al (2004) for common soil types found in the Southeast region of Queensland State, Australia. The soils were classified according to the Australian Soil Classification (Isbell 2002). This work was based on detailed field investigations and soil sampling to assess the important soil physical and chemical properties that influence the ability of a soil to provide suitable renovation of effluent. The outcomes of multivariate statistical analysis of the collected soil physical and chemical characteristics were used to provide a soil renovation suitability for the different soil types assessed.

Although this research provided a thorough assessment of the different soil types and their renovation ability, the suitability ranking was developed using natural soils that had not been used for effluent treatment. However, in order to strengthen the practical nature of the suitability ranking, a soil's effluent renovation ability is best assessed based on the changes soils undergo with the application of sewage effluent.

This paper describes the outcomes of a research study undertaken to assess the soil suitability for renovating effluent using undisturbed soil columns. The main aim was to investigate the ability of the different soils to provide suitable attenuation and removal of sewage effluents, and in particular nutrients (nitrogen and phosphorus). The changes in the soil's textural and physico-chemical makeup were investigated to assess long term impacts due to effluent application. Discriminant Analysis (DA) was utilised to allow classification of the various soil characteristics and to identify relative changes in each soil after the application of effluent.

## **Materials and Methods**

### **Soil Column Setup**

Six undisturbed cores were obtained representing the major soil types commonly found in the Southeast region of Queensland State, Australia. The six soil types included Kurosol, Ferrosol, Podsol, Sodosol, Dermosol and Chromosol soil groups (Isbell 2002). Table 1 gives the relevant physical and chemical soil properties of the six soil cores and their respective soil classifications based on the Australian Soil Classification and equivalent Soil Taxonomy Order (NRCS 1999), together with a general soil profile description. The undisturbed cores were obtained using an 85mm hollow flite auger and driven to a depth of 1300mm. The internal hollow tube was retracted and the soil core was transferred to a 100mm diameter, 2000mm long PVC tube to provide secure conditions for transportation of the samples to the laboratory. Whilst in storage in the laboratory the cores were periodically sprayed with deionised water to prevent the soil from drying out. This was to ensure that no unintentional cracks occurred through the soil structure that may provide preferential flow paths to occur.

Test columns, as depicted in [Figure 2](#), were fabricated using 100mm  $\phi$  Perspex tubing capped with a 10mm thick square Perspex base plate. Three effluent sampling points were located along the length of each column at 150, 450 and 800mm from the top. A fourth effluent sampling point was centrally located at the base. Additionally, three soil sample ports were located at the same heights but opposite to the effluent sampling points. Effluent samples were collected from the soil columns using 75mm long stainless steel tubes (10mm  $\phi$ ), which were inserted through the soil at each effluent sampling point. Sampling bottles were attached to each effluent sampling point using PVC tubing. Fifteen predrilled holes (3mm  $\phi$ ) were positioned along the top and sides of the steel tube to allow percolating effluent to enter and flow out into connected sample bottles.

Prior to inserting each soil core into the prepared columns, the top 400mm was removed. This was to replicate as closely as possible the installation depth of a typical soil absorption system commonly used in Australia ([Figure 1](#)). The collected soil cores were carefully inserted into the prepared test columns to minimise any disturbance. The gap between the soil core and the column was filled with liquefied petroleum jelly to prevent any preferential flow between the soil core and the column wall and to ensure that all applied effluent would infiltrate through the soil.

### **Effluent Application and Sampling**

Primary treated effluent collected from a municipal sewage treatment plant was applied to the top of the column at the rate of 240 mL/day until ponding occurred due to the formation of a clogging mat. The effluent application rate was based on typical household effluent flow rates and system sizes, and adjusted (scaled) for the cross-sectional of the soil column. Average quality characteristics of the effluent used is given in [Table 2](#). After effluent ponding had taken place, application rates were reduced to 120mL/day to allow sufficient time for effluent to percolate through the clogging mat and infiltrate into the soil. A reduction in effluent infiltration as a result of the clogging mat occurred over a 3-4 month period before steady state infiltration occurred. Effluent application to all six soil columns continued over an eight month period. Effluent which had infiltrated through the soil column were collected and analysed on a weekly basis or earlier if the sampling bottles were full. The collected

samples were analysed for pH, Electrical Conductivity (EC), Total Kjeldahl Nitrogen (TKN - organic and ammonia nitrogen) and Phosphorus ( $\text{PO}_4^{3-}\text{-P}$ ).

### **Soil Sampling and Analysis**

Samples were also taken from the soil cores prior to their insertion into the test columns to determine the original physico-chemical characteristics of each soil type. The results obtained are given in [Table 1](#). Subsequently, soil samples were collected at each of the three soil sampling points in the test columns after eight months of effluent application. This was to evaluate the changes to soil physico-chemical characteristics after long term effluent application. The soil parameters measured and the test methods adopted for analysis are given in [Table 3](#).

### **Discriminant Analysis (DA)**

To assess the ability of the different soil types for renovating effluent, discriminant analysis (DA) was employed to discriminate between major soil characteristics influencing the relevant processes. Discriminant analysis is a multivariate statistical analysis technique where a data set containing X variables is separated into a number of pre-defined groups using linear combinations of analysed variables. This allows analysis of their spatial relationships and identification of the respective discriminative variables for each group ([Wilson 2002](#)) Objects that retain similar variances in the analysed variables will have similar discriminant scores, and therefore when plotted, will cluster together. Likewise, relationships between variables can be easily identified by the respective coefficients. Strongly correlated variables will generally have the same magnitude and orientation when plotted, whereas uncorrelated variables are typically orthogonal to each other. There are two main functions for which DA is commonly employed. Firstly, it is used to analyse the differences between two or more groups of multivariate data using one or more discriminant functions in order to maximally separate the identified groups. Secondly, DA can be employed to obtain linear mathematical functions which can be used to classify the original data, or new, unclassified data, into the respective groups ([Brereton 1990](#)).

Due to the ability of DA to classify objects according to specific variables, DA has been used in soil analysis successfully to classify unknown soil properties into

respective known classes. For example, [Wilson \(2002\)](#) used stepwise discriminant analysis to distinguish between Palaeocene and Plio–Pleistocene chalk deposits using particle size and heavy metal data from 276 samples. DA provided good differentiation between the clustered chalk deposits, and successfully allowed for the classification of unknown chalk deposits. [Splechna and Klinka \(2001\)](#) used DA to identify relationships between field identified and measured soil nutrient properties. Similarly, DA provided excellent classification (>70%) of the field identified and measured soil properties. However, in the case of the study discussed in this paper, as the soils were already classified, DA was adopted for its grouping functionality in order to identify variations in the soil types. Analysis of the soil column data was achieved by undertaking DA on the different data using statistiXL ver 1.3 ([statisiXL 2003](#)). To evaluate the suitability of the six different soil columns for renovating effluent and to assess changes throughout the soil profile due to effluent application, three DA analyses were performed.

Initially DA was undertaken to distinguish between the major physico-chemical characteristics of the various soil types used, based on a selection of variables employed to evaluate the soil's ability to renovate effluent. The variables for the initial DA were pH, EC, organic matter (%OM), cation exchange capacity (CEC), effective cation exchange capacity (ECEC), exchangeable sodium percentage (ESP) and percent clay (%C). These initial variables were selected based on the suite of tests generally carried out in land resource evaluation ([Rayment and Higginson 1992](#)). These tests have been developed through extensive agricultural research and are designed to distinguish between deficient, adequate and toxic availability of elements in soil and between degraded and non-degraded soil conditions. These parameters have recently been more widely used to assess the attenuation and removal of effluent pollutants from onsite wastewater treatment systems. Additionally, these parameters also match with variables selected for analysis in research undertaken by [Carroll et al \(2004\)](#) for developing a soil suitability framework for effluent renovation.

DA was also used to analyse the obtained soil data to assess the various changes occurring in the soil columns as a result of long-term effluent application. Three data sets were constructed including the original soil data and soil data obtained after effluent application. Firstly, the same suite of variables used in the previous DA were

re-analysed with the additional soil data obtained after effluent application. The variables were pH, EC, %OM, CEC, ECEC, ESP and %C. This was undertaken to assess the changes in the soil as a result of effluent application. Secondly, DA was also undertaken using the variables pH, EC, Cl<sup>-</sup>, CEC, %OM, %C, TKN, NO<sub>3</sub><sup>-</sup>-N, PO<sub>4</sub><sup>3-</sup>-P and TP. This was to assess how successful the different soil types were at accumulating and removing effluent pollutants, particularly nitrogen and phosphorus. pH, EC, %OM, CEC and %C were also used to help discriminate the soils based on the parameters that have a major influence on effluent renovation. Thirdly, DA was undertaken on the soil's individual cation data to assess the impact effluent had on soil cations and respective ionic charges. The data set used for analysis included pH, CEC, ECEC, %C, ESP, Ca:Mg ratio, Al, Fe, Mg, Na, Ca.

## **Results and Discussion**

### **Effluent results**

Analysis of the effluent samples taken from the column indicated that four out of the six columns assessed provided suitable attenuation and removal of effluent pollutants. However, only two columns (Columns 2 and 5), were permeable enough to allow the effluent to percolate through the entire soil column. Table 4 provides the average concentrations of effluent constituents and average percentage removal of nitrogen and phosphorus after passing through the individual soil core. Columns 2, 4, 5 and 6 provided > 90% reduction of both nitrogen (TKN) and phosphorus (PO<sub>4</sub><sup>3-</sup>-P) applied to the soil. However, the reduction in TKN may not necessarily be specifically related to attenuation. Most of the TKN will eventually undergo nitrification and denitrification, depending on the characteristics of the soil, in particular the presence of aerobic and anaerobic conditions. Subsequently, some or all of the TKN may be nitrified and allowed to move through the soil as NO<sub>3</sub><sup>-</sup>-N. The level of removal of nitrogen as a species will therefore depend on the ability of the soil to denitrify the existing nitrate.

In the study, most of the nitrogen was observed to be removed or nitrified by the time the effluent had infiltrated to the second sampling point, except for Column 2 and 3.

Column 2 was successful in reducing only 42% of the TKN by the second sampling point, but had been removed 99% by the time the effluent had reached the third sampling point. The main reason for this is most likely due to Column 2 having a lower clay fraction in the upper soil horizons, with increasing clay content down through the profile. As shown in the soil's mineralogy, it had a mixed mineralogy in the upper horizons with the smectite found in the lower B horizon. Smectite typically retains high CEC levels, which would explain the high removal in the lower half of the column. Column 3 was a sandy soil which had a low CEC and OM content, indicating that inadequate conditions exist for suitably adsorbing nitrogen. Increases in the level of TKN at the third sampling point are most likely due to ponding of effluent lower down in the column, thereby increasing TKN concentrations. Due to the high permeability of the sand in Column 3, percolating effluent was found to discharge from the base of the column within 1-2 hours. As the applied effluent infiltrated through the soil at a faster rate than the effluent could pass out through the lower sampling points, ponding occurred. Subsequently, ponding in the lower half of the column would also provide anaerobic conditions, thereby causing an accumulation of TKN at the base due to poor nitrifying conditions.

A majority of the phosphorus content discharged with the effluent was already adsorbed by the soil by the time the effluent had infiltrated to the second sampling point, except in Column 3. Column 3 was only capable of removing 30% of the phosphorus, and in fact, effluent samples taken from the first two sampling points had higher levels of  $\text{PO}_4^{3-}\text{-P}$  than the initial effluent. This suggests that the sand has poor adsorption ability, and subsequently, the nutrients were being desorbed and transported through the soil with the percolating effluent, into the lower reaches of the soil profile. As was the case for nitrogen, the high permeability allowed transportation of  $\text{PO}_4^{3-}\text{-P}$  through the column, allowing accumulation and increase in concentration in the lower half of the column. In a field situation, this is a cause for major concern. Sandy soils, similar to that in Column 3, although successful in removing larger solid particles, will not be particularly effective in removing the smaller particulates or soluble pollutants.

Columns 1, 4 and 6, although showing that most pollutants were being removed by the soil, were not receiving any effluent from below the second sampling point. The

effluent was only able to infiltrate through the soil very slowly, indicating that the permeability of these soils was quite slow. The possibility of a restrictive layer (an impermeable layer of soil such as impermeable clay or hardpans) within the soil Column may also explain this occurrence. In order for a soil to provide suitable renovation of effluent, it must first be able to infiltrate through the soil at a rate appropriate to provide adequate treatment and also the disposal of the effluent. However if the rate is too slow, discharged effluent will not be able to infiltrate through the soil, and ponding will occur.

### **Discriminant Analysis of Soil Results**

Results from the DA undertaken on the original soil data signified that most of the soils had distinct differences in their chemical makeup, and clustered based on their respective soil classifications. Soil types that had similar soil properties, for example column 5 and 6, did however cluster closely together, although the respective clusters were still distinct. [Figure 3](#) provides a DA scores plot of the soil analysis for six soil columns. In the DA analysis, 96.3% of the variance was contained in the first two discriminate functions, and these were therefore considered in the analysis.

The main factors contributing to whether a soil can be considered suitable for effluent renovation was CEC, %OM, the type and content of clay present and permeability. As highlighted in [Figure 3](#), three soil columns, Columns 1, 2 and 4, all have satisfactory levels of CEC, %OM and %C. This is typical, as generally a significant amount of CEC is attributed to the available organic matter in the soil, with the remaining CEC related to the clay content and type and the individual cations present in the soil. ([Oorts et al 2003](#)). This is shown in the DA ([Figure 3](#)) with these variables being strongly correlated. Furthermore ECEC, based on the contribution of individual cations, is related to the soil CEC, but not to %OM, as shown in [Figure 3](#).

Columns 5 and 6 are more highly correlated with the ECEC and ESP. The results of original soil samples from Columns 5 and 6 suggest that these soils could be sodic in nature, as indicted by the higher levels of ESP in the soil itself. Typically, sodic soils have a high proportion of sodium ions in relation to other cations. A high proportion of Na ions on the clay mineral exchange weakens the bonds of the corresponding clay particle when the soil is moistened, causing the clay to swell and disperse ([Irvine and](#)

Reid 2001). Subsequently, through the derivation of ESP the concentration of Na is inversely proportional to the CEC, as depicted in Figure 3. However, the discrimination of column 6 is scattered on function 1, with more discrimination based on ECEC, rather than ESP. Therefore, individual cations other than Na are more likely to have significant concentrations in Column 6. Column 4, however, retains high ESP values which agree with its original classification of a Sodosol. This poses a significant issue in relation to this particular soil's ability to treat effluent. Additional Na added to the soil via the applied effluent may cause the clay particles to disperse, consequently reducing the soil's infiltration and effluent renovation ability. Column 3, a Podsol is grouped by itself, mostly due to this soil having relatively very low CEC and little organic matter. Columns 3, 5 and 6 have the strongest relationship with permeability,  $k$ . Although Column 3 has the highest permeability of all columns. It also has the weakest correlations with the other variables. As such, the overall correlation with  $k$  is reduced.

From the initial DA (Figure 3), it can be observed that Columns 1, 2 and 4 (Kurosol, Ferrosol and Sodosol soil types respectively) indicate that, based on the physico-chemical parameters, they will be the most suitable for effluent renovation. This corresponds well with the soil suitability rankings described by Carroll et al (2004). However, Sodosol soils (Column 4) should be assessed with caution due to their inherent tendency to disperse. The original soil conditions may indicate that the Sodosol soil is satisfactory for effluent renovation, but the soil structure may deteriorate over time, particularly if there is a high concentration of Na present in the effluent. Column 5 (Dermosol), although having a reasonable CEC, has lower levels of %C and %OM, slightly reducing its overall renovation ability. A majority of the available CEC is developed from the individual cations present in the soil. However, due to the higher permeability of this soil, the time required for the appropriate exchanges to take place between the effluent and cations may be relatively too short.

Chromosol soils (Column 6) were classified as being suitable with regards to effluent renovation in terms of its chemical characteristics, but again caution must be exercised. Due to the abrupt changes in clay content which can occur in these soils, a high percentage of clay lower down in the soil profile will result in poor effluent infiltration, thereby reducing the overall ability of the Chromosol soil for effluent

renovation. The Chromosol soils investigated by [Carroll et al \(2004\)](#), although having abrupt changes in clay content, still retained a significant proportion of sand, resulting in adequate permeability to treat effluent. The Chromosol soil investigated in the current laboratory study also had an adequate permeability, but did not have a high CEC, consequently reducing its overall suitability. The DA analysis highlights that Column 3 obviously provides the lowest ability for the renovation of effluent amongst the investigated soils. It has the lowest CEC, %OM and ECEC levels, and therefore has little pollutant attenuation and removal capabilities. Column 3 also had the highest permeability, and due to its poor renovation ability, most pollutants will be transported rapidly through the soil matrix.

[Figure 4](#) shows the DA undertaken on the original soil column data and after effluent application (retaining 82.1% of the total data variance within the first two discriminant functions). It indicates that substantial changes have occurred within the soil matrix due to the infiltration of effluent. This is mostly in relation to increases in the level of organic matter introduced to the soil. All soil columns, except Column 6, showed increased organic matter throughout the column and in most cases had the highest increases within the top section of the Column. Column 3 exhibited the largest increase in soil organic matter, primarily due to the small amount of organic matter present in the original soil. Column 6, however, showed little accumulation of organic matter at the first sampling point, but had significant increases at the second and third sampling points. Due to increases in the organic matter content, increases in the respective CEC levels were also noticeable, with Columns 1, 2 and 5 showing substantial increases.

Contrastingly, even though the CEC of all columns increased, the ECEC was in fact found to decrease in some columns. This can be expected for two reasons. Firstly, increases in organic matter increased the overall CEC, as already discussed. Secondly, the individual cations which contribute to ECEC, may have been desorbed from the clay particles with the percolating effluent, and either migrated further down through the soil column or washed out with the effluent through the sampling points. Individual cations in the effluent were not analysed during the present study. Changes in the ECEC were most noticeable in Column 3. However, all soil columns were found to have reductions in ECEC to some degree.

ESP was shown to increase for Columns 2, 4 5 and 6, most probably due to increase in Na present in the effluent itself. The largest increase was in Column 1 at the first sampling point and at all sampling points in Column 4. The increase in Na in Column 4 also resulted in minor reductions in permeability throughout the column. Obviously, the sodic nature of this soil along with increase in Na from the effluent is causing the soil to disperse, thereby reducing the permeability and effectiveness of the soil to treat effluent.

Increases in pH and EC for all columns except Column 3 were observed. This is to be expected as sewage is generally alkaline. Column 3, being a Podosolic soil from a saline environment, had a high EC with a near neutral pH. Consequently, the EC will inevitably reduce over time due to the lower EC of the applied effluent. However, due to the applied effluent having a pH of 8.0, the subsequent pH of the soil in Column 3 slightly increased.

In relation to the sewage effluent renovation ability of the soil, the initial DA analysis corresponds well with the results achieved by [Carroll et al \(2004\)](#). Primarily columns 1, 2 and 4, which were classified as the most suitable soils for effluent renovation based on the chemical analysis, were also found to be suitable using DA. Columns 5 and 6 matched with the medium classification, whereas Column 3 was also found to be unsuitable for renovation of effluent. However, although the initial analysis collaborated well with previous research, further assessment was necessary to ensure that the different soil types investigated were suitable for effluent renovation. Analysis of the six columns performance in relation to contaminant attenuation and removal, particularly the major nutrients of nitrogen and phosphorus, was subsequently undertaken

[Figure 5](#) provides the DA undertaken to analyse the soils' ability for removing pollutants. From the analysis, 81% of the total data variance was retained in the first two discriminate functions. As indicated by this plot, two significant clusters are evident. These clusters highlight the soils' ability to attenuate or remove nitrogen and phosphorus. In this particular analysis, increases in the soil nutrient content indicate that higher attenuation levels are being achieved. Soils which originally had high CEC

and %OM levels should be suitable for renovating effluent, subject to other physical and chemical characteristics such as %C and permeability. Columns 1, 2, 4 and 5 had increases in the level of organic matter and consequently the overall CEC. Column 3 is an exception, as although increases were found, they were minimal. On the other hand, very little increase in %OM was observed in Column 6, however, a significant reduction in CEC was apparent in. Subsequent to effluent application, Columns 1, 2, 4 and 5 all show a high increase in TKN and TP, which would be accounted for due to the soil adsorbing these. Increases in  $\text{NO}_3^-$ -N concentrations in Columns 1, 2, 4 and 5 however, suggests that a substantial proportion of the organic nitrogen (TKN) is also being converted to  $\text{NO}_3^-$ -N, which is typically not adsorbed to soil particles.

Column 3 however showed little accumulation of nutrients. In fact, it was observed during the experiment that the effluent extracted from the columns had higher levels of nutrients than the original effluent over the first three months of the experiment. This was due to the poor adsorption characteristics of the soil where the percolation of effluent caused the nutrients to desorb and wash off nutrients in the soil. Levels of  $\text{PO}_4^{3-}$ -P was highest in Columns 3 and 6. Column 6 also had low levels of nutrients after effluent application, indicating that either little adsorption of nutrients had taken place or the effluent was unable to percolate through the soil matrix or possible preferential flow was occurring, bypassing the soil sampling points. As the %C in Column 6 is not high, this suggests that poor adsorption ability is the most likely explanation. DA on the initial data ([Figure 3](#)) shows that Column 6 does in fact have a lower CEC and OM content than the other columns, indicating poor nutrient attenuation ability. Nitrate levels were also found to have increased with high levels found in Columns 1, 2, 4 and 5, indicating that the free movement of  $\text{NO}_3^-$  through these soils is reduced, as compared to Columns 3 and 6.

The final DA analysis assessing the individual cations (retaining 83.1% of the total data variance within the first two discriminant functions) as shown in [Figure 6](#) indicated two major soil clusters were evident. Column 4 was clustered individually based on the level of Na and Mg ions present in this soil. This is not surprising as this soil retains sodic conditions. Ca tends to aid more in the flocculation of soil particles, whereas Mg and Na are more likely to cause dispersion ([Dawes and Goonetilleke 2003](#), [Emerson 1977](#)) Consequently, soil with Ca:Mg ration  $<0.5$  typically imply high

ESP and high exchangeable Na. On the other hand, soils with moderate to high CEC, Ca:Mg >0.5 having dominant Ca or Mg over Na (and therefore low ESP) have a higher ability for effluent renovation without major soil structure breakdown (Dawes and Goonetilleke 2003).

All remaining soil columns had similar discrimination of the Al, CEC and ECEC variables, and were discriminated mostly by Al, Ca, Ca:Mg ratio and pH. Significantly, most columns showed similar patterns with reductions in Ca, and increase in Al. Due to the reduction in Ca, the Ca:Mg ratio also reduced accordingly. Columns 3 and 6 were distinguished by increases in Al and Fe and subsequently also had distinctive increases in the ECEC. Columns 1, 2 and 5 had reductions in Al and Fe, but increases in Ca and Na. The reductions in Al and Fe are most likely due to these cations being desorbed and washed off the soil particles by the percolating effluent. For Al, this phenomenon typically occurs in soils that have low pH which can cause the clay particles to deteriorate thereby releasing the aluminium ions (Brady and Weil 2002, Gustafsson et al 2001). These desorbed ions are subsequently replaced by Ca and Na which typically have high concentrations in effluent. Most soil columns, except Column 4, also showed slight reductions or had no change in concentrations of Mg. After effluent application, columns that had reduced Mg levels, also had increased Ca:Mg ratio, due to the Ca becoming more dominant.

### **Soil Suitability**

Discriminant Analysis of the soil physico-chemical data indicates that two of the six undisturbed soil columns investigated in this study provided adequate attenuation and removal of effluent pollutants, and retained sufficient permeability through the soil matrix to continue receiving effluent. This is confirmed by the substantial reductions in nitrogen and phosphorus in the effluent samples collected after passing through the soil cores. Column 2 and 5 (Ferrosol and Dermosol) both showed reductions of >90% for both phosphorus and nitrogen without major reductions in soil permeability, thereby indicating satisfactory performance over a long time period. Columns 1, 4 and 6 (Kurosol, Sodosol and Chromosol soils respectively), although indicating that removal of pollutants in the effluent is highly achievable, reductions in the soil permeability over eight months of effluent application point to the fact that these soils may not be able to adequately treat effluent over the long term. Therefore, alternative

means of treatment and disposal, such as increasing the effluent disposal area, regular replacement of the disposal area or providing alternative treatment systems to soil adsorption trenches may be required. However, in the case of these particular soils it is important to thoroughly investigate them prior to designing the effluent disposal system in order to ensure adequate effluent renovation will occur. Column 3 (Podosol) had the poorest renovation ability, indicating poor pollutant attenuation and removal. Column 3 also has a high permeability, which reduces the time available for appropriate ionic exchanges between pollutants and the soil to occur, as well as providing a means to transport pollutants through the soil and into groundwater.

## **Conclusions**

The use of undisturbed soil cores to assess the suitability of different soil types for renovating effluent indicated that soils that have an initial high CEC, %OM, medium %C and a medium permeability are more suitable. In this study, soil columns that had a very high %C did not sufficiently transmit applied effluent through the soil column to allow continued long term application. Likewise, it was observed that soils with a high permeability, and low CEC, %OM and %C did not provide sufficient attenuation and removal of effluent pollutants prior to the effluent exiting the column. Therefore, from the results of this study, it can be concluded that Ferrosol and Dermosol soil types provide the most satisfactory conditions for the proper treatment and disposal of sewage effluent. Kurosol, Sodosol and Chromosol soils provided a suitable treatment level. However, reductions in the soils permeability over the time of the experiment indicates that these soil types may have problems with adequately disposing of effluent from onsite systems in the long term. Lastly, the Podosol soil provided very poor treatment ability to treat effluent, indicating that sandy soils with high permeability and little ionic exchange capacity are not suitable for subsurface treatment and disposal of effluent.

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Table 1 Selected soil physico-chemical characteristics

Parameter	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Soil Classification (Isbell 2002)	Kurosol	Ferrosol	Podosol	Sodosol	Dermosol	Chromosol
Soil Taxonomy (NRCS 1999)	Alfisols or Ultisols	Oxisols	Spodosols	Alfisols	Utisols	Alfisols
Soil Profile Description	Soils with a clear or abrupt textural B horizon Major part of B horizon is strongly acidic	Soils with B horizon with free iron oxide content >5% Fe in fine earth fraction (<2mm).	Soils that have Bs, Bhs or Bh horizons	Soils with clear or abrupt textural B horizon Upper 0.2m of B2 horizon is highly sodic (ESP >6%)	Soils with B2 horizon with more developed structure	Soils with a clear and abrupt textural change in B horizon (abrupt increase in clay content)
Clay (%C)	31.6	83.1	0.2	19.6	24.9	21.8
Silt (%Si)	25.3	2.1	6.5	21.7	3.9	10.9
Sand (%S)	43.1	14.8	93.3	58.7	71.2	67.3
Clay Mineralogy	Kaolinite Some Smectite in lower B horizon	Kaolinite Mixed KI in upper horizons and Smectite in lower B horizon	Kaolinite	Kaolinite	Kaolinite	Kaolinite
pH	4.7	4.5	6.0	4.9	5.0	6.1
EC $\mu$ S/cm	122	47.3	649.3	924.3	150.9	384.3
Organic Matter (%OM)	11	18	1.6	12.6	4.7	6.5
CEC meq 100g <sup>-1</sup>	39.5	48.7	10.6	43.6	30.5	17.1
ECEC meq 100g <sup>-1</sup>	31.3	48.4	9.4	23.1	20.9	11.2
TKN mg/Kg	111.4	156.3	168.2	243.8	189.1	175
NO <sub>3</sub> <sup>-</sup> -N mg/Kg	15.7	7.7	23.7	28	50.3	33.3
PO <sub>4</sub> <sup>3-</sup> -P mg/Kg	0.7	0.4	0.3	0.6	0.7	0.2
TP mg/Kg	2.3	1.3	0.5	0.9	1.5	0.7
ESP (%)	0.9	0.2	1.1	7.2	0.8	2.6

Table 2 Average Effluent Characteristics of applied effluent

Parameter	Concentration
pH	8.00
EC mS/cm	0.98
NO <sub>3</sub> <sup>-</sup> -N mg/L	4.00
TKN mg/L	8.80
PO <sub>4</sub> <sup>3-</sup> -P mg/L	1.00

Table 3 Soil Sample analysis methods

Parameter		Analytical Method
pH	Soil	4A1: pH of 1:5 soil/water suspension at 25°C (Rayment and Higginson 1992)
	Effluent	TPS-81 pH-conductivity meter
Electrical Conductivity (EC)	Soil	3A1 EC of 1:5 soil/water suspension at 25°C (Rayment and Higginson 1992)
	Effluent	2520-Conductivity (APHA 1999)
Chloride ions (Cl <sup>-</sup> )	Soil	5A1 chloride 1:5 soil/water filtered suspension at 25°C (Rayment and Higginson 1992) and measured using 4500-Cl E Automated Ferricyanide Method (APHA 1999)
	Effluent	4500-Cl E Automated Ferricyanide Method (APHA 1999)
Total Kjeldahl Nitrogen (TKN = organic + ammonia)	Soil and Effluent	Wet oxidation method (Kjeldahl 1983) 4500-Norg C (APHA 1999)
Nitrates (NO <sub>3</sub> <sup>-</sup> )	Soil only	7CB1 Water Soluble Nitrate 1:5 soil/water filtered suspension at 25°C (Rayment and Higginson 1992) Measured using 4500-NO <sub>3</sub> <sup>-</sup> F Automated Cadmium Reduction (APHA 1999)
Orthophosphate (PO <sub>4</sub> <sup>3-</sup> )	Soil	9G2 Acid extractable phosphate 1:200 soil/0.005M H <sub>2</sub> SO <sub>4</sub> at 25°C (Rayment and Higginson 1992) and measure using 4500-P C Vanadomolybdophosphoric Acid Colourmetric method (APHA 1999)
	Effluent	4500-P F Automated Ascorbic Acid Reduction (APHA 1999)
Total Phosphorus (TP)	Soil only	Digestion of soil using 4500-P F Automated Ascorbic Acid Reduction (APHA 1999)
Organic Matter (%OM)		Sol oxidised with 50% H <sub>2</sub> O <sub>2</sub> and heated to 1300°C to burn organic matter. Weight loss difference equal to organic matter content
Cation Exchange Capacity (CEC)		Ammonium selective electrode method (Borden and Giese 2001) Ammonia Standards made as per 4500-NH <sub>3</sub> E (APHA 1999)
Effective Cation Exchange Capacity (ECEC)		ECEC = exchangeable cations + exchangeable acidity = (Ca + Mg + Na + K) + (Al + H)
Exchangeable Cations (Al, Fe, Mg, Na, Ca and K)		Measured using Varian AA6 Flame Atomic Absorption Spectrophotometer. Acetylene flame used to measure Fe, propane used to measure Na and K, and nitrous oxide used to measure Ca, Mg and Al
Exchangeable Sodium Percentage (ESP)		ESP = (100 x Exchangeable Na <sup>+</sup> )/ECEC
Soil Mineralogy (Clay type)		Samples prepared using method developed by Bish and Post (1989) Mineralogy determined via X-ray diffraction using Phillips PW1050/25 vertical goniometer, with a graphite diffracted beam monochromator
Particle Size Distribution: Percent Clay (%C), Silt (%Si) and Sand (%S)		Determined from Soil mineralogy measured using X-ray diffraction

Table 4 Average effluent characteristics of effluent collected form soil columns

Column	Sampling Point	pH	EC	NO <sub>3</sub> <sup>-</sup>	TKN	PO <sub>4</sub> <sup>3-</sup> -P	TP	%NH <sub>3</sub> Removal	%PO <sub>4</sub> Removal	Total Volume of Effluent L
1	1	6.75	506.75		3.68	0.08		58.2	92	5.0
	2	6.20	352.60		0.98	0.02		88.9	97.8	
	3	~	~	~	~	~	~			
2	1	6.21	663.71		6.21	1.01		29.4	0*	4.8
	2	5.08	45.00		5.08	0.11		42.3	89.5	
	3	4.70	7.00		0.01	0.01		99.9	99	
3	1	5.81	855.67		44.33	1.45		0*	0*	4.8
	2	4.61	883.67		41.67	9.76		0*	0*	
	3	4.39	905.7	~	6.63	25.6	~	24.7	0*	
	4	3.96	421.3		1.53	0.7		82.6	30	
4	1	6.21	181.15		0.81	0.37		90.8	63	5.5
	2	5.60	12.00		0.10	0.01		98.9	99	
	3	~	~	~	~	~	~			
5	1	6.87	365.25		1.94	0.22		78.0	78	6.0
	2	5.80	178.25		1.00	0.26		88.6	74	
	3	4.80	15.18		0.02	0.09		99.8	91	
6	1	6.82	137.43		1.04	0.04		88.2	96	5.6
	2	6.00	61.50		0.70	0.01		92.0	99	
	3	~	~	~	~	~	~			

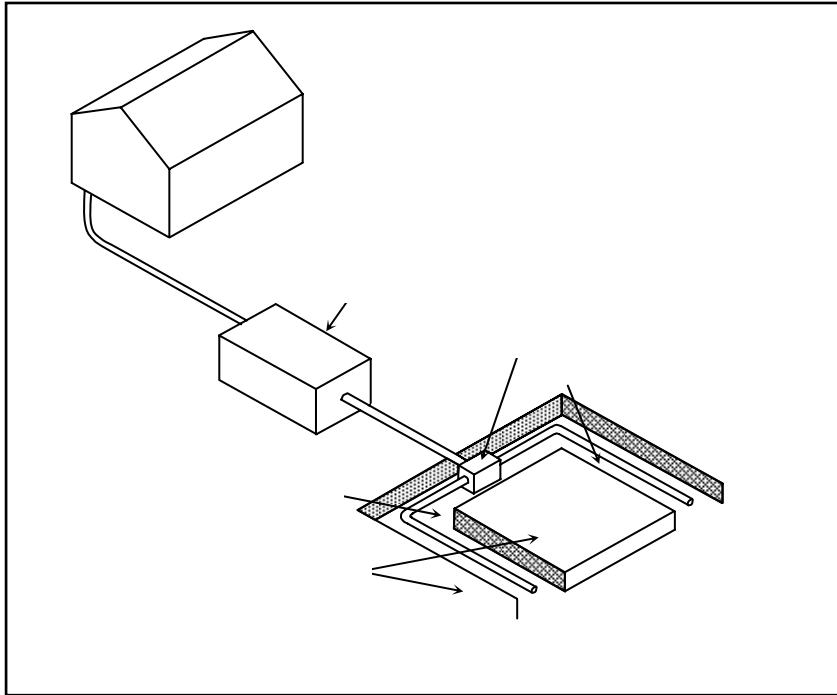


Figure 1: Typical septic tank-soil adsorption system used in Australia

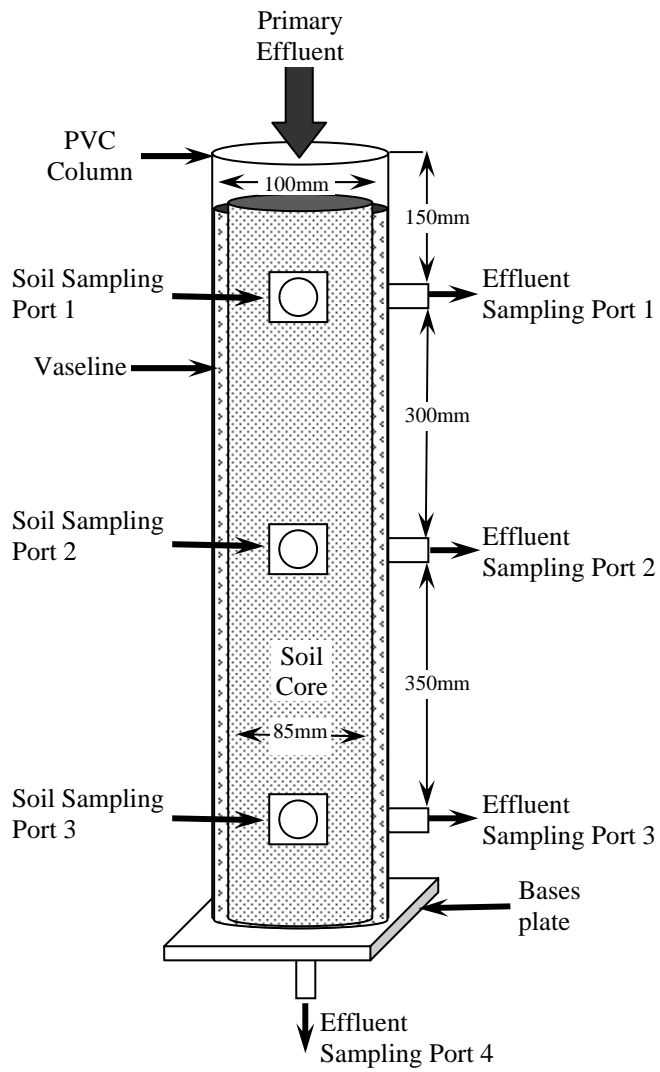


Figure 2: Soil column setup

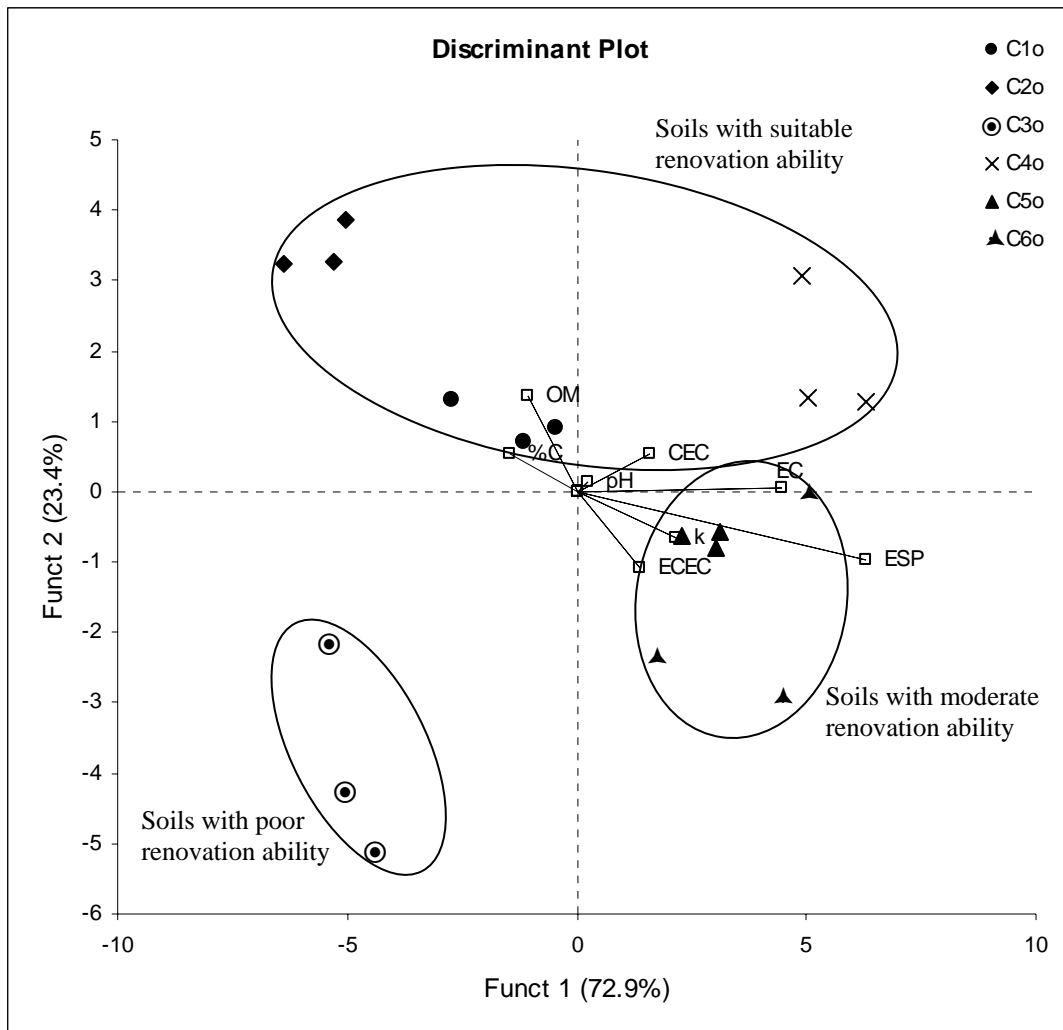


Figure 3 Discriminant Plot of original soil data. Legend: 'o' original soil

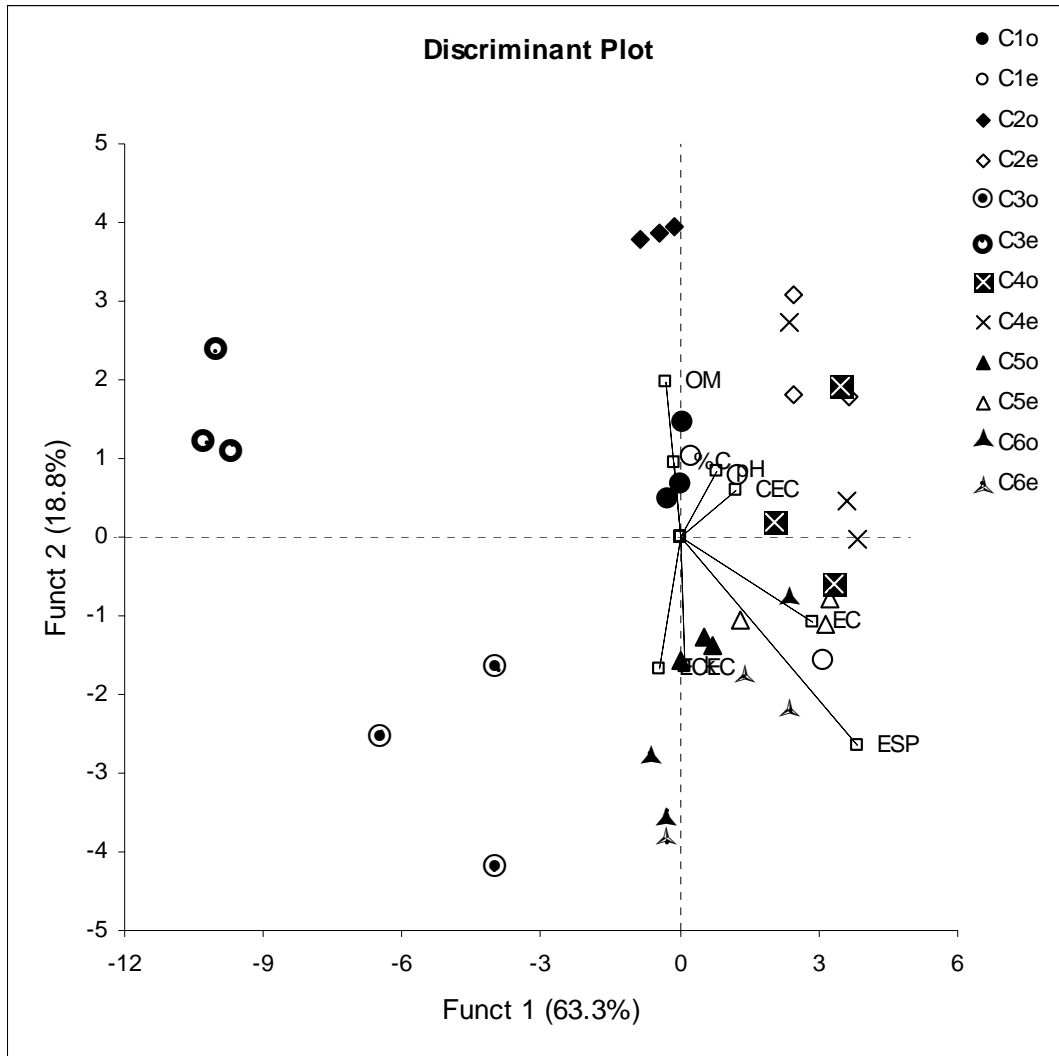


Figure 4: Discriminant Plot of soil data prior to and after eight months of effluent application. Legend: 'o' original soil, 'e' after effluent application

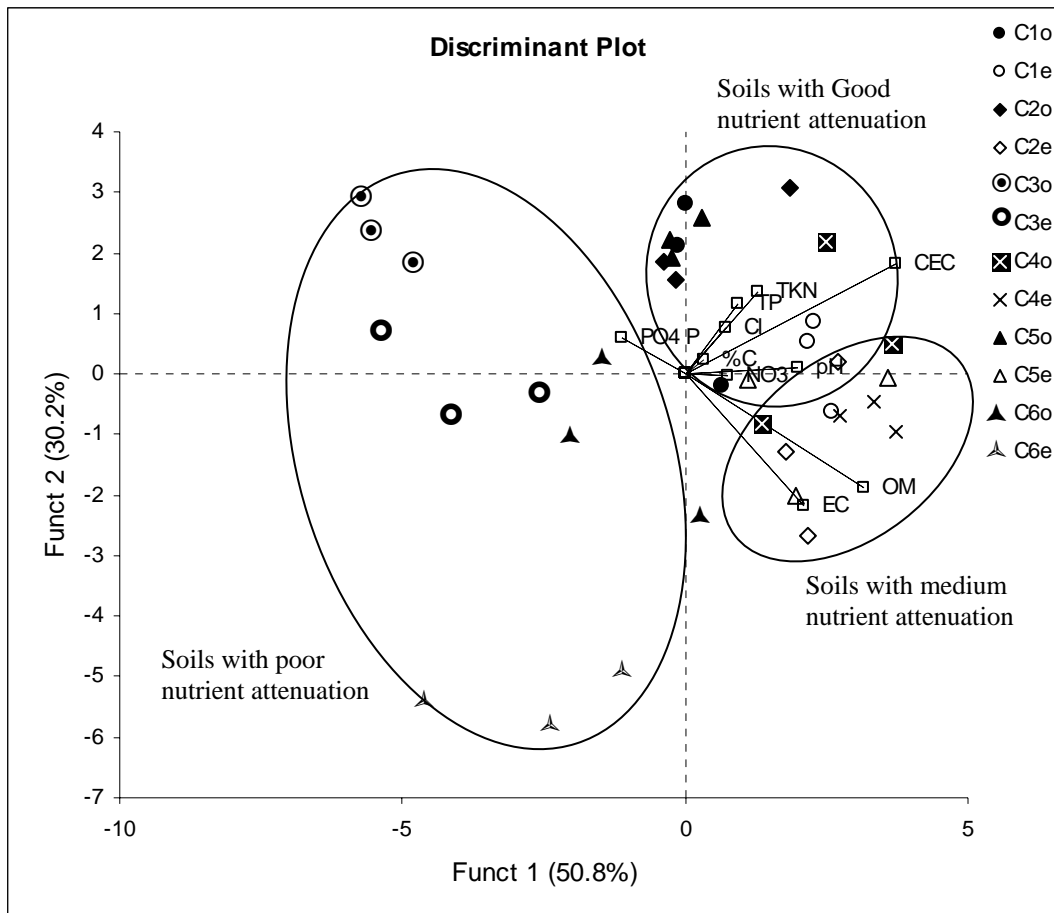


Figure 5 Discriminant plot of soil nutrient and selected physico-chemical data indicating soils that have suitable effluent renovation ability. Legend: 'o' original soil, 'e' after effluent application

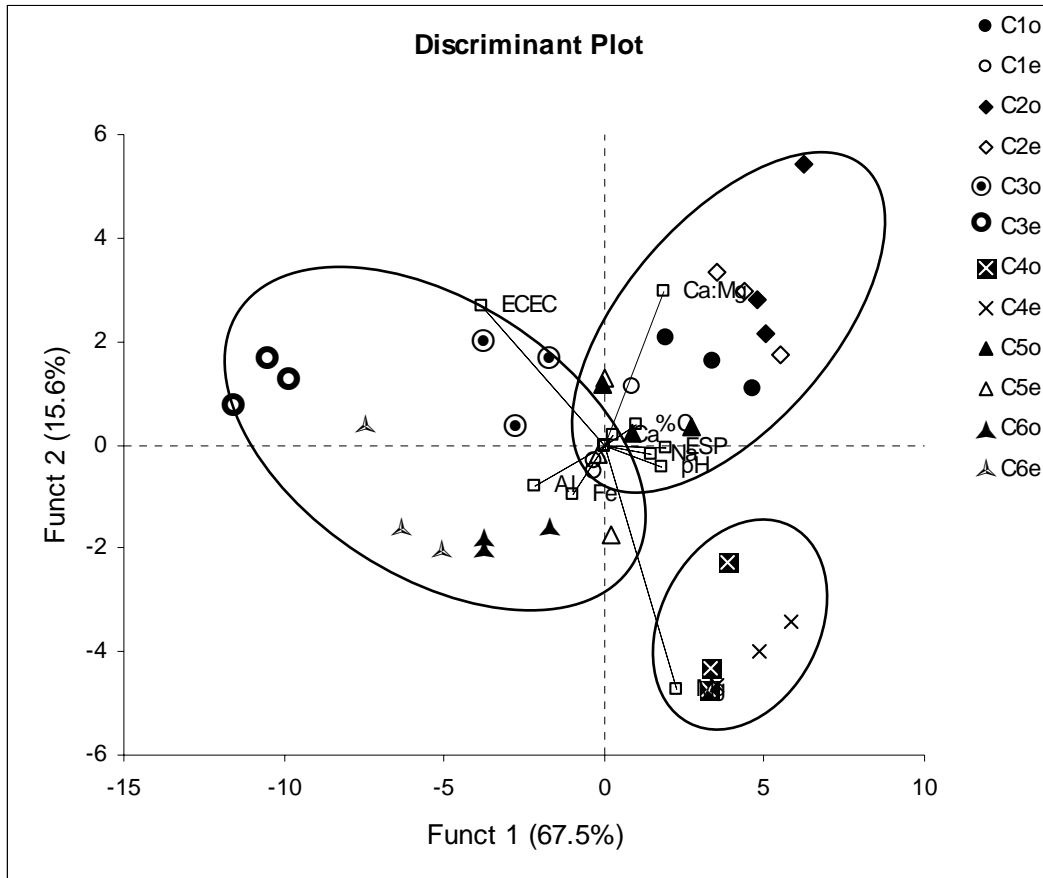


Figure 6: Discriminant plot of soil individual cations. Legend: ‘o’ original soil, ‘e’ after effluent application

