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USE OF UNDISTURBED SOIL COLUMNS TO EVALUATE SOIL CAPABILITY TO RENOVATE ON-SITE SEWAGE TREATMENT SYSTEM EFFLUENT

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ABSTRACT

The objective of this study was to assess soil capability for the renovation of effluent from on-site sewage treatment systems for a number of different soil types commonly present in Queensland, Australia. Undisturbed soil cores from 12 different sites were collected by a hollow hydraulic auger to a depth of approximately 1400mm. Primary treated sewage effluent with the following characteristics; 8.2 mg/L as NO_3-N, 0.79 mg/L as PO_4^{3-}, pH 7.89, EC 0.9 ds/m and COD 185 mg/L was applied to the soil columns. Due to the heterogeneity of the soil structure and its chemical characteristics, the soil capability for removing effluent contaminants varied widely. The results for the sandy soil types reported an 80% removal in the nitrate, phosphorus and salt content after 240mL flow; then the concentration of nutrients started to increase significantly in effluent samples collected from the lower section of the sandy soil columns**.** The wash-off of the accumulated salts and ammonia fixation resulting from the high organic matter content in this region of the columns. The soils with heavy clay content and a high cation exchange capacity provided 95% nitrate and total phosphorus removal and 50% salt reduction in the first few centimetres of the columns. Also, some soils were relatively impermeable due to the amount and type of the clay present in the soil which prevented the effluent from percolating through the columns. This resulted in effluent ponding on the surface for long periods of time. It is hypothesised that in the effluent ponding situations, the effluent would need to find an easier and more convenient path to percolate through the soil such as lateral flow and the evapotranspiration would play a key role in reducing the ponded effluent.

KEYWORDS. On-site sewage treatment systems, Mineralogical analysis, Nitrogen, Phosphorus, Soil suitability.

INTRODUCTION

The land application of effluent from on-site sewage treatment systems has been increased due to the increasing number of houses being built in areas not serviced with central reticulated sewage treatment systems. In general, on-site sewage treatment systems could offer an environmentally acceptable means of waste disposal, where the soil and the site conditions are suitable for effluent applications. Discharging effluent however, over a poorly structured soil with weak physical and chemical characteristics can lead to serious environmental consequences, such as degradation of the soil surface and the groundwater. The soil must therefore have suitable characteristics that will enable it to handle effluent application and remove effluent contaminants before the leachate reaches the ground water body.

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Cotton et al., (1996); and Gardner et al., (1997) reported that effluent filtering through soil is subjected to a number of physical and chemical processes that lead to removal of effluent pollutants. Pollutant removal from on-site septic tank effluent, generally by filtering through subsurface layers of the soil, requires a comprehensive understanding of the physico-chemical process involved in the transport and removal of nutrients such as phosphorus and nitrogen. The primary soil factors associated with nutrients removal are soil structure, water table level and dissolved oxygen, organic matter content and exchangeable cation.

The cation exchange capacity (CEC) of a soil refers to the amount of positively charged ions (cations) a soil can hold. The CEC of the soil is controlled by the proportion and mineralogy of clay and/or organic matter that is present (White, 1997). These two colloidal substances are essentially the nutrient reservoirs of the soil.

Soils that contain kaolinite have a CEC ranging from 3 to 20 meq/100g, while soils that contain smectite have a much larger CEC, ranging from 60 to 136 meq/100g (Borden and Giese 2001). In addition, the organic content in the soil also helps to increase the adsorption capacity of the soil by providing extra surface area available for exchangeable cations (Morrás, 1995). The soil CEC, influenced by the organic matter and clay contents, are considered the most important soil data available to quantify the soil's capacity to renovate discharged effluent.

EC is an important parameter for evaluating the salt ion concentration in the soil. A high concentration of salts in soil can lead to salinity problems. Soils are considered to have a salinity problem when the total soluble salt concentration is high enough to affect plant growth. The soils are classified as saline, saline-sodic or non saline-sodic, depending on the chemical composition of salts present in the soil (Shaw et al., 1987).

Soil evaluation based on physico-chemical analysis was used in this study to evaluate different soil capabilities to treat and handle on-site effluent application. Twelve undisturbed soil cores with varying soil characteristics were selected, utilising a comprehensive field investigation and soil analysis from undeveloped and unsewered areas. The objective of this research study was to investigate the capabilities of the different soil types to ameliorate effluent from on-site sewage treatment systems.

MATERIALS AND METHODS

Undisturbed Soil Cores

The project area was located in Logan City, which is a major regional population centre in the State of Queensland, Australia. Approximately 50% of the Logan region does not have a reticulated sewerage system and in these areas on-site sewage treatment systems with septic tank-subsurface effluent disposal are being utilised.

Soil suitability for on-site sewage effluent application was evaluated by subjecting twelve different undisturbed soil cores from the Logan City region with secondary effluent collected from Loganholme Water Pollution Control Centre, located 30 km south of Brisbane. The wastewater samples were collected from the primary tank in 20-litre drums and transferred to the laboratory. The collected effluent was sieved to reduce the large particles content, and stored in 1 litre containers, the samples were then frozen until required to be used.

The soil cores were collected based on a preliminary field and soil physico-chemical investigations. Several issues were considered when selecting the different soil types and locations, such as planning, environmental sensitivity, previous soil physico-chemical analyses and soil availability in the area. The Australian Soil Classification system by Jacquier, (2000) was used to identify the different soil types for the twelve selected sites (Table 1). Undisturbed soil cores were utilised to estimate the soils behaviour under on-site effluent applications in the field.

The soil cores were collected using a hollow auger with a 85mm internal diameter hollow steel tube inside a 200mm flite. The flite auger was placed on the ground surface and first driven hydraulically into the soil to a depth of 900mm. The internal hollow steel tube was retracted, the split spoon opened and the soil core transferred to a 100mm diameter, 2000mm length of PVC tube, to provide secure conditions to transport the samples to the laboratory.

Experimental Soil Columns

Twelve Acrylic columns were prepared prior to the collection of the soil cores. The PVC columns were 100mm in dimeter and 1000mm in length. Three effluent sampling points were located down the length of the soil columns at different heights (170, 300 and 350mm). Three soil sampling windows were located at the same heights as the sampling points, on the opposite side of the acrylic columns. The acrylic columns were supported by a square base (150x150mm), with a final outlet sampling point for the effluent exiting the soil core. A schematic diagram of the experimental soil columns is shown in Figure 1.

Geo-textile filters were positioned at the bottom of the acrylic column and at each effluent sampling point to reduce the amount of soil fines entering the sample collection points. The top 250mm of the collected soil cores were disregarded, as this is the usual depth of soil removed for the disposal trench in the field. Soil cores of 900mm were separated from the initial undisturbed soil cores to provide soil samples for the required physico-chemical analysis. The 900mm soil cores were then carefully placed into the acrylic columns to prevent any disturbance to the soil structures.

The gap between the soil core surface and the inner surface of the Acrylic column was filled with a liquefied clear Vaseline to force the effluent to percolate through the soil, rather than taking the path of least resistance down the side of the acrylic column. The Vaseline having been heated to a temperature of 50^oC, was pumped continuously to the base of the soil core through a heated copper tube. The Vaseline was pumped continuously until the gap was completely filled up to the soil core surface.

A hollow stainless steel collection tube 75mm in length with a 10mm external diameter was inserted into the soil column at each effluent sampling point. A series (15) of holes 3mm in diameter were distributed along the collection tube to facilitate the collection of the effluent from the different soil depths. The top of the soil cores were covered by a 30mm gravel to provide the necessary surface area for the micro-organisms growth, clogging mate formation and storage for effluent infiltration.

Australian Soil Classification	**Description**	**Equivalent Soil Taxonomy Order (NRCS 1999)**
Salic Hydrosol	• Light brown at A-horizons with low organic matter content. • Mottled yellow dark clayey colour at B-horizon	Ultisols or Inceptisols
Red Ferrosol	• Low organic matter content at the soil surface • Deep red sandy soil at A-horizon • Creamy white layer at B-Horizon	Oxisols
Aeric Podosol	• Low organic matter content at the soil surface • Sandy soil with a high leached organic matter at 1300 mm depth	Spodosols
Black Sodosol	• Grey sandy with deep organic matter content • Light brown colour at B-horizon	Alfisols
Red Dermosol	• Medium brown colour with rich organic content at A-horizon • Creamy clayey B-horizon	Utisols
Brown Kurosol	• Moderate brown sandy colour at A-horizon • Light brown clayey colour at B-horizon	Alfisols or Ultisols[1]
Brown Vertosol	• Medium brown sandy with low organic content at A-horizon • Mottled clayey layer with reddish brown colour at B-horizon	Vertisols
Brown Dermosol	• Light brown sandy with low organic matter content at A-horizon • Deep clay layer with medium brown colour.	Utisols
Yellow Dermosol	• Dark brown sandy rich organic matter content at A-horizon • Light brown sandy clay layer	Utisols
Yellow Chromosol	• Medium dark brown sandy layer high organic matter content at A-horizon • Orange brown silt clayey layer at B-horizon	Alfisols
Grey Chromosol	• Light medium brown colour with rich organic matter at A-horizon • Orange clayey at B-horizon	Alfisols
Red Kandosol	• Sandy layer with high organic matter content in A-horizon • Red yellow sandy medium texture at B-horizon	Alfisols or Ultisols[1]

Table 1. Selected Soil Descriptions.

[1] Classification is dependant upon the quantity of base cations

Experimental Sample Analysis

The physico-chemical analyses for the soil and effluent were undertaken according to following procedures. The soil samples were initially dried at 50^0C and sieved with a 2mm sieve. The soil pH and electrical conductivity (EC) were measured using a soil/water ratio of 1:5 at 25^0C. The soil pH and EC measurements were conducted according to the method (4A1 pH of 1:5 soil/water suspension) defined by Rayment and Higginson (1992) and effluent analysis according to APHA (1995). The cation exchange capacity (CEC) was measured using the ammonia selective electrode method developed by Borden and Giese (2001). The ammonia ion-selective electrode used was a HNU systems Inc. model ISE-10-10-00. The electrode was connected to an Orion Research Inc. model 720A pH/ISE Meter. The ammonia standards were made by diluting freshly prepared 0.1 M ammonium chloride according to method number 4500-NH_3 E as defined by APHA (1995). A Labcono Freeze Dryer 4.5 77500 was used to dry the soil samples. Centrifugation was performed using a MSE Centra-4 centrifuge at 3000 rpm to collect the solid soil sample.

To determine the soil's organic matter content (OM), 10 mL of 50% hydrogen peroxide (H_2O_2) was initially added to the 20 g soil sample and heated for 24 hours at 105 ^{0}C. The dried soil samples were then crushed and subjected to a temperature of 1300 ^{0}C for 1 hour, where the calculated weight loss was taken as the total organic matter content. Total nitrogen in the soil was measured by the wet oxidation method Total Kjedahl Nitrogen (Kjedahl 1993). The organic nitrogen in the soil sample was analysed by converting the soil organic nitrogen to NH_3-N by digestion in the presence of a catalyst. The digestion method adopted from the HACH (1988) manual, and the analytical method adopted from APHA (1995). The ammonia selective electrode method developed by Borden and Giese (2001) was adapted to measure the level of ammonia in the digested solution. All ammonium standards were made by diluting freshly prepared 0.1 M ammonium chloride according to method number 4500-NH_3 E as defined by (APHA, 1995). Phosphorus and nitrogen in the effluent was measured according to method 4500-P defined in the APHA (1995).

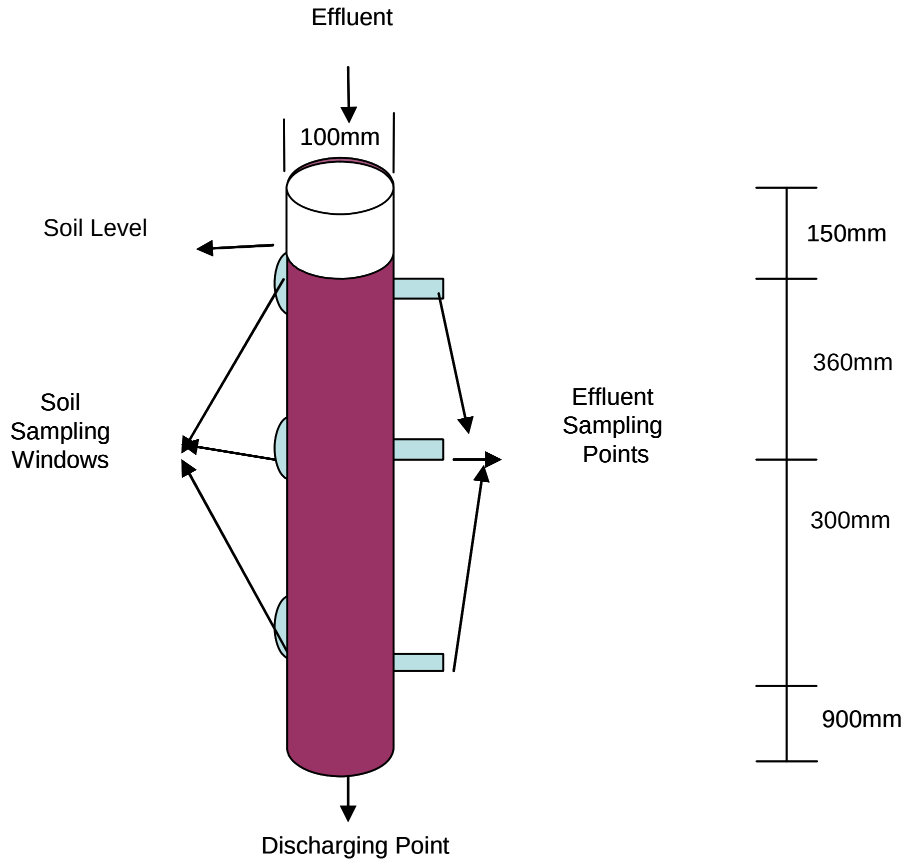

Figure 1. Schematic diagram of the soil columns.

RESULTS AND DISCUSSION

Primary treated sewage effluent with the following characteristics; 8.2 mg/L as NO_3-N, 0.79 mg/L as total phosphorus, pH 7.89, Electrical conductivity 0.9 dS/m and chemical oxygen demand 185 mg/L was applied to the soil columns. The effluent was applied at a flow rate of 240 mL/day until the effluent started ponding on the soil column surface, when it was then applied only when needed.

The effluent samples from the column sampling points were collected over an eight month period. The summarized results are presented in Table 3. The total amount of effluent applied to each column varying due to the different soil permeability's. Initially the soil columns loaded 240ml/day for the first two weeks due to the high percolation rate. This was then greatly reduced once the soil was fully saturated and started forming a crust layer at the soil column surface. In general, several factors effect the effluent percolation rate through the soil such as formation of the biological mate and the development of dispersed clay particles. An increase in the exchangeable sodium cations on the clay surfaces, supplied by the effluent will result in a sodicity problem causing the clay particles to disperse and thereby reducing the soil permeability. The soil behaviour varied from among columns and the following observation and comments were derived for each type of soil. The soil ranking in this stage of the undertaken research was considered based on the following criteria, the soil considered a low suitability to renovate effluent if the nutrients removal were less than 60% and CEC was ranged between 1 and 10 meq/100g. The soil considered having a moderate suitability to renovate effluent if the nutrients removal were ranged from 60 to 80% and the CEC ranged between 10 and 50 meq/100g. Finally, the soil was considered highly suitable if the nutrients removal was over 85% and CEC over 50 meq/100g. The combination of the soil ranking was presented in Table 2.

Table 2 Soil Suitability Ranking

Suitability	**Nutrients Removal**	**CEC(meq/100g)**
Low	low	Low
Low	Low	Medium
Medium	Low	High
Low	Medium	low
Low	High	Low
Medium	Medium	Medium
High	High	High
High	Medium	High
High	High	Medium

The Salic Hydrosol had an average nitrogen removal of 50% and average phosphorus removal of 90%. The results were for effluent samples collected from the upper and the middle sampling points (about 440 mm below the top soil surface). The level of nitrogen removed is relatively low when compared to other columns. The phosphorus sorption however, is considerable due to the organic matter content in the top section of the soil column. Therefore, from the preliminary analysis based on the CEC, organic matter content and the level of phosphorus and nitrogen removal this soil can be classified as having moderate suitability for effluent treatment.

The Red Ferrosol provided an average nitrogen removal of 85%, 95% phosphorus removal and 10% EC reductions. These values were calculated using effluent samples from the upper sampling point only, as no effluent has been collected from the middle or lower sampling points to date. The low level of EC reduction will increase the possibility of salt accumulation, resulting in salinity problems in the future which has been a major concern of by the Australian authorities.. Nitrogen and phosphorus removal are reasonably high when compared to the other columns. The dominant clay type was found to be kaolinite by 57% and illite by 27%. The kaolinite was the least active clay but the illite content improved the soil adsorption capacity through the soil horizons. Smectite content was detected at the lower B-horizon, which has a swelling capacity, this soil type will therefore swell with the application of the effluent. Significant soil swelling can reduce the pathways available for effluent percolation, as seen by the progressive ponding of the effluent on the soil column. Though the soil shows a reasonable reduction in the nutrient levels, its performance during the wet season is questionable due to the transmission of effluent. Therefore, this soil has been classified as moderately suitable for on-site effluent treatment.

The Aeric Podosol exhibited no reduction in the levels of nitrogen and phosphorus. The soil in this column was the least effective for sewage treatment when compared with the other soil columns investigated. Additionally, the concentration of the nitrate and phosphorus in the effluent started to increase significantly (around 500% of the initial deposition) at the samples from the middle sampling point at the soil column after closing the lower sampling collection point. This increase in nutrient levels would result from the leachate washing the organic matter down from the soil surface to the lower B-horizon which has been observed and examined, the build-up of organic matter content at B-horison was increased from less than 1% to reach 8% after the two months effluent application.. The nutrients previously adsorbed onto this organic material will then be released into the effluent from this layer. After the mineralogical analysis this soil was found to be predominately quartz, As a result of this soil's high permeability and the obtained soil physico-chemical analysis, this soil is classified as having a low capacity for effluent treatment

Black Sodosol reported an average of 85% nitrogen and 40% phosphorus removal with 55% EC reduction. However, all the results obtained for the upper sampling point (about 60 – 100 mm below the top). Effluent ponding was occurred, which could be due the dispersing of the clay in the soil based on the soil physico-chemical analysis which indicated that this soil has a high exchangeable sodium percentage averaged 17% before effluent application, also the soil fertility based on Ca: Mg ratio indicated that this is not fertile (>0.5%). This conclusion based on the mineralogical analysis of the soil, which showed that the dominant clay type is kaolinite in addition to a small portion of smectite. Therefore, the soil dispersed and the soluble salts accumulated in the soil column. Also, effluent ponding occurred on the soil surface, which will lead to lateral flow of effluent. This soil can be classified as a moderate soil for effluent treatment but special care is needed in the designing of the subsurface effluent disposal area due to effluent ponding.

The Red Dermosol provided an average nutrient removal of 65% for the nitrogen and 40% for the phosphorus, with a 30% reduction in the EC. All the effluent samples were again collected from the upper sampling point and effluent ponding occurred on the soil surface due to the heavy clay content. This soil will initially be classified as having a low capability to treat sewage effluent.

The Brown Kurosol, Brown Vertosol, Yellow Chromosol, and the Red Kandosol, were found to have high degree of contaminant removal, with up to 99% nitrogen and phosphorus reductions, and a 95% reduction in the EC. Most of these soils exhibited a high percolation rate and effluent samples were collected from the upper, middle and to a lesser extent from the lower sampling points. From the physico-chemical analysis of these soils, the CEC is in the range 20 to 50 meq/100g and the organic matter content is around 9% of the total weight of soil. After application of the effluent to the Brown Kurosol there was a reduction in the Quartz and Kaolinite contents

(Figure 2) in the soil sampled from the upper sampling point, possible due to the migration of the fine soil particles or due to the build-up of amorphous material in the soil which reduced the percentage of quartz and kaolinite in the analysed soil samples after effluent applications. There was also an increase in the amorphous content (organic matter from the effluent) in the soil samples as would be expected. Based on the data evaluation, these soils are considered suitable for effluent treatment.

Table 3.Summary of Outcomes from the Soil Column Study

Soil Type	**Sampling Point.**	**% Removal**				**Soil Data**		
		Nitrogen	**Phosphorus**	**EC**	**TCOD**	**pH**	**CEC Meq/100g**	**OM %**
Salic Hydrosol	1	53-55	91-93	47-51	65-68	6.08	16.0	20.0
	2	68-92	98-99	50-60	80-90	4.71	32.0	7.90
Red Ferrosol	1	86-92	93-96	Feb-14	72-80	5	45	22.0
Aeric Podosol	1	None	None	Jul-22	27-43	5.27	10.0	4.13
	2	None	None	0-11	32-62	6.41	13.8	0.02
	3	0-20	None	0-11	65-75	6.21	8.00	0.32
	Discharg	68-77	30-82	0-86	74-75	~	~	~
Black Sodosol	1	82-93	37-48	25-97	71-87	4.65	35.0	10.18
Red Dermosol	1	53-80	32-51	20-30	50-71	5.82	9.20	8.00
Brown Kurosol	1	71-86	42-66	48-86	64-84	4.47	11.27	2.23
	2	95	91	90	94	4.49	25.2	5.10
	3	99	99	100	98	6.2	27.08	13.1
Brown Vertosol	1	75-77	90-99	58-61	82-97	5.81	17.0	3.12
	2	92	89	88	99	5.34	28.0	2.89
	3	100	90	100	100	3.99	52.0	8.00
Brown Dermosol	1	75-87	85-92	82-98	93-96	4.30	15.2	10.01
	2	94	99	97	97	4.49	9.42	9.42
Yellow Dermosol	1	45-88	88-92	41-52	69-75	5.12	13.0	2.13
	2	93	99	70	93	5.38	28.0	3.26
Yellow Chromosol	1	35-80	Dec-46	31-50	54-76	5.01	11.0	3.91
	2	87	91	67	90	5.20	32.0	5.22
	3	99	99	93	98	5.60	54.0	6.81
Grey Chromosol	1	86-91	99	76-80	88-94	6.22	18.0	5.03
Red Kandosol	1	71-87	86-92	50-70	76-85	5.91	8.0	3.00
	2	88	90	72	92	6.03	16.0	5.30
	3	100	98	88	97	5.65	45.0	11.9

The Brown Dermosol and the Yellow Dermosol provided a high degree of nutrient removal with 90% nitrogen and up to 95% phosphorus removal. Less favorable results however, were recorded for the salt concentrations, with only a 50% reduction in the EC. These soils were found to have a high organic content in the A-horizon, which would assist with the up-take of phosphorus and nitrogen fixation. The level of adsorption capacity is also controlled by the type of clay present in the soil. The type of clay found in these soils was predominately kaolinite (30%), with a smaller percentage (15%) of a mixed layer of illite and smectite, the percentage of minerals were obtained from the XRD analysis, the software provided these calculations. The presence of the more unstable smectite clays would result in large amounts of soil swelling. This soil is classified as moderately suitable for effluent treatment, especially if there is a controlled effluent application. Extra care should be given to the design of the subsurface effluent disposal area.

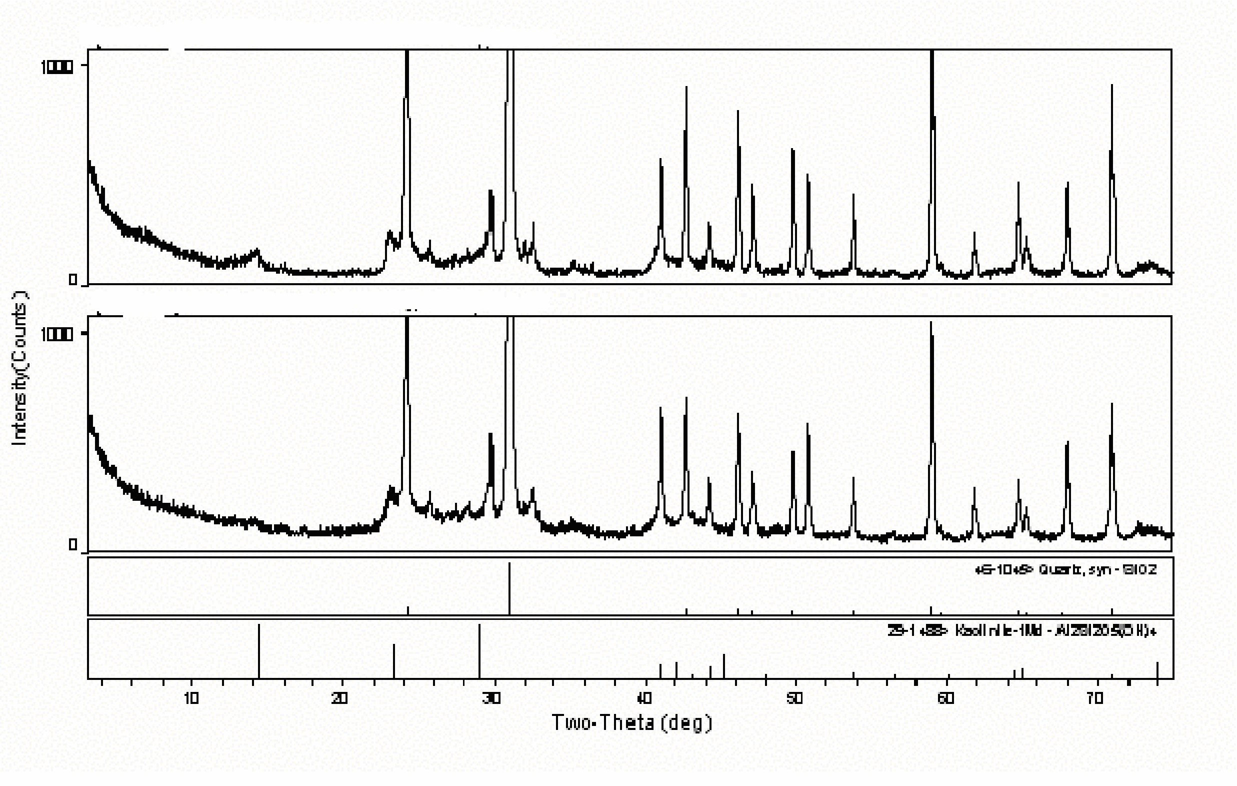

Figure 2. Mineralogical Analysis of the Brown Kurosol before and after effluent application

The Grey Chromosol was found to provide 85% nitrogen removal, 95% phosphorus removal and a 75% reduction in the EC. All the effluent samples were again collected from upper sampling point due to the low percolation rate of the effluent through the soil column. The mineralogical analysis showed that the dominant clay type was smectite, thereby causing the possibility of soil swelling and dispersion.. The smectite clay present in this soil could provide excellent treatment under slow effluent application. Excessive application of effluent however, will force the effluent to move laterally to find an easier path to travel. According to the results from the mineralogical and physico-chemical analyses this soil is considered suitable for effluent treatment. However, due to the possibility of soil swelling and dispersion from the presence of illite, extra care should be given to the design of the subsurface treatment system.

Soils with pH values close to 4.5 are classified as being moderately to extremely acidic. Acidic soils can become a problem for biological activity, which will affect the soil fertility when the pH drops to below 5.5, due to the rise in aluminum availability from the breakdown of clays. The soils investigated in this study had pH ranging from 4.5 to 6.0. Soils that have either a low clay contents and/or a low pH with high concentrations of soluble toxic metal ions, will eliminate some of the biological processes that are beneficial to sewage effluent renovation, such as nitrification or ammonia fixation (White, 1997). It is therefore important to consider the site pH levels when evaluating the site suitability for effluent treatment.

CONCLUSION

The twelve soil types selected for this study had varying capacities for treating on-site sewage effluent. The results from this research indicate that the type of the clay present in the soil controls the soil's behavior when they are subjected to on-site sewage effluent The soil samples utilised in this study had CEC varying from 1 to 86 meq/100g and The electrical conductivity (EC) of the soil samples varied between 0.8 and 9 ds/m. Excessive effluent application, even to a soil that is considered suitable for effluent treatment, may lead to effluent ponding, causing serious environmental problems. If ponding occurs in the field, the effluent would need to find a more convenient pathway to percolate through the soil; this could be achieved through lateral pathways. Evapotranspiration however, would also play a key role with removing the ponded effluent.

The outcomes from this research identify the varying soil capabilities for effluent treatment. The results from the soil column experiments depicted that 40% of the selected soils are suitable for effluent application, 40% are moderately suitable, with the remaining 20% completely failing to treat the effluent. The soils that are classified as moderately suitable however, need extra care when designing the subsurface and effluent distribution system.

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