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# Leachate characteristics as influenced by application of anaerobic baffled reactor effluent to three soils: a soil column study

I.B. Bame [a,*], J.C. Hughes [a], L.W. Titshall [a,1], C.A. Buckley [b]

[a] Soil Science, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville 3209, South Africa
[b] Pollution Research Group, School of Engineering, University of KwaZulu-Natal, Durban 4041, South Africa

## HIGHLIGHTS

- Adsorption/leaching processes occur in pulses during intermittent leaching.
- Nutrient concentration balance indicates retention of major plant elements.
- Leachate characteristics are a function of the soil type and leaching solution.
- P supply from effluent could meet requirements for maize in contrasting soils.
- The Ca:Mg ratio of effluent is of importance to retention and leaching of cations.

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## ABSTRACT

A soil column study was undertaken in the laboratory with three contrasting soil types namely a sandy soil (Longlands (Typic Plinthaquult), E horizon), an organic soil (Inanda (Rhodic Hapludox), A horizon) and a clayey soil (Sepane (Aquic Haplustalf), A horizon). Anaerobic baffled reactor (ABR) effluent was leached through the soil and distilled water was concurrently used as a control. The effluent was slightly basic (pH 7.4–7.6), had heavy metal concentrations below permissible limits for irrigation purposes and contained plant nutrients such as P, S, Ca, Mg, and K. Results indicated that after application of 16 pore volumes, the concentrations of $Ca^{2+}$ and $Mg^{2+}$ were lower in the leachates than in the original effluent indicating adsorption by the soils and $Mg^{2+}$ was preferentially adsorbed to $Ca^{2+}$. Phosphorus was strongly adsorbed in all soils. While its adsorption in the Inanda could be attributed to organic matter and the presence of iron oxides and oxyhydroxides, the clay type and amount in the Sepane was likely responsible for P adsorption. The $NO_3^-$–N, which was initially low in the effluent, increased as leaching progressed while the $NH_4$–N decreased. A chemical balance to ascertain loss or gain of major elements from the effluent application indicated P to be strongly immobilised from the effluent representing 41, 6 and 10 fold the fertilizer needs for maize in the Inanda, Longlands and Sepane, respectively. Results obtained indicated that the chemical composition of ABR effluent is significantly altered when leached through soils with distinct properties.



## 1. Introduction

The use of treated wastewater in agricultural soils has been proposed as a sustainable management strategy and an aspect of integrated water management for water-poor countries (Neubert, 2009). In peri-urban areas of many developing countries, agriculture would be virtually impossible without the use of wastewater for irrigation (Scott et al., 2004; Marsalek et al., 2005; Hamilton et al., 2007; Keraita et al., 2008). Farmers are dependent on it for their existence since it is their only reliable source of water (Friedler, 2001; Rutkowski et al., 2007) although it contains not only appreciable amounts of plant nutrients but also trace toxic metals (Pescod, 1992). Although the concentrations of heavy metals in domestic sewage effluents are generally low, long-term use of these wastewaters on agricultural land often results in a build-up of these metals in soil (Mapanda et al., 2005). Environmental concerns of wastewater use are mainly directed towards nitrate and phosphorus leaching and polluting groundwater and eutrophication of surface water bodies (Kretschmer et al., 2003; Qadir et al., 2010; Bar-Tal et al., 2011). However, monitoring effluent infiltration and the replacement of the existing soil solution with fresh effluent can provide relevant short-term information on these changes (Gloaguen et al., 2007).

* Corresponding author. Tel.: +27 332605422; fax: +27 332605426.
*E-mail address:* bongsiysi@gmail.com (I.B. Bame).
[1] Present address: Institute for Commercial Forestry Research, P.O. Box 100281, Scottsville 3209, South Africa.

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An anaerobic baffled reactor (ABR) treating domestic wastewater converts a large amount of wastewater chemical oxygen demand (COD) to methane gas, and reduces pathogen loads but with no nutrient removal (Foxon et al., 2005). Large amounts of ammonium and phosphorus in ABR effluent limits its direct discharge to surface or groundwater but it can be used for irrigation of agricultural land (Foxon et al., 2004). Such wastewater treatment plants are currently being proposed for use in South Africa. Soils are generally better suited as a reservoir for wastewater than water bodies because of their ability to buffer and assimilate the water, nutrients and any contaminants (Bond, 1998) through physical, chemical and microbial processes with eventual conversion to less toxic forms. An evaluation of the soils retention capacity of elements from effluent and the composition of leachates as a result of this retention will give a better understanding of the ability of soils to impact on effluent characteristics. This study evaluates: (i) the changes in leachate characteristics after ABR effluent application to three contrasting soils and; (ii) the capacity of these soils to retain plant nutrients from the applied effluent.

## 2. Materials and methods

### 2.1. Soils

#### 2.1.1. Physical, chemical and mineralogical characteristics

The experiment was carried out using three contrasting soil types namely the A horizon of an Inanda (Ia; humic A, red apedal B, weathered dolerite), the E horizon of a Longlands (Lo; orthic A, E, soft plinthic B), and the A horizon of a Sepane (Se; orthic A, pedocutanic B, unconsolidated material with signs of wetness) (Soil Classification Working Group, 1991). These correspond to a Rhodic Hapludox, Typic Plinthaquult, and Aquic Haplustalf, respectively, according to the USDA Soil Taxonomy (Soil Survey Staff, 2010). The Ia was collected from World's View, Pietermaritzburg under commercial forestry; the Lo from the South African Sugar Research Institute, Mt Edgecombe previously under sugarcane then grassland for about 12 years; the Se from a permaculture site at Newlands–Mashu, near Durban. Soil was collected, air-dried and milled to pass through a 2-mm mesh prior to preparing the soil columns. Soil pH was measured in distilled water and in 1 M KCl solution (1:2.5 soil:solution) (Rowell, 1994) using a Radiometer PHM 210 meter. Electrical conductivity (EC) was measured in distilled water (1:2.5 soil:solution) using a CDM 210 electrical conductivity meter with temperature correction for 25 °C. Organic carbon was determined by the dichromate oxidation method (Walkley, 1947) and particle size distribution by the pipette method (Gee and Bauder, 1986). Other analyses were carried out by the Soil Fertility and Analytical Services Division (Department of Agriculture, Cedara) following methods given by The Non-Affiliated Soil Analysis Work Committee (1990).

The clay mineralogy of the three soils was estimated qualitatively using X-ray diffraction (Bühmann et al., 1985). Specimens were run on a Philips PW1050 diffractometer using monochromated CoK$\alpha$ radiation from 3° to 40° 2$\Theta$ at 1° per minute scan speed with a 0.02° Counting interval.

### 2.2. Anaerobic baffled reactor (ABR) effluent

The effluent was collected from a pilot prototype ABR located at the School of Engineering, University of KwaZulu-Natal (UKZN), Durban, South Africa, which was fed manually with domestic sewage and produced about 100 L of effluent in 24 h. The single batch of effluent was collected one week before use and stored under refrigeration at 4 °C.

The effluent was analysed prior to each leaching event. The pH and EC were measured as in Section 2.1.1. The P, K, Ca, Mg, S and heavy metals (Fe, Mn, Cu, Zn, Cd, Cr, Co, V and Se) were analysed by inductively coupled plasma emission spectrometry (ICP, Varian 720-ES); $NO_3^-$–N and $NH_4^+$–N with a TRAACS 2000 continuous flow auto-analyser. Total carbon was measured with a Shidmadzu TOC analyser. Sulphur was then converted to the sulphate ion by calculation. The *Escherichia coli* count was done by plating dilutions from the column on eosin methylene blue agar plates and counting colonies formed after incubation at 35 °C for 48 h (American Public Health Association, 1992).

### 2.3. Column study

The columns consisted of polyvinyl chloride tubes, 20 cm long (inner diameter = 5.3 cm). A perforated perspex disc (holes of 0.8 cm diameter) covered with nylon mesh was inserted at the bottom of each column. Glass–fibre mesh was placed on the disc inside the column before filling with soil to minimise sediment loss from the column during leaching. The columns were filled with soil to a height of about 17 cm by uniform tapping on the bench top to achieve a bulk density of 1480 kg m$^{-3}$ for the Lo, 750 kg m$^{-3}$ for the Ia and 1120 kg m$^{-3}$ for the Se soil; values equivalent to field bulk densities. Glass–fibre mesh was placed on the soil surface to minimise soil disturbance during the leaching procedure.

Soil columns were leached with either effluent or distilled water in triplicate (18 columns). Prior to leaching all columns were saturated with distilled water by capillary wetting. With an assumed particle density of 2650 kg m$^{-3}$, a pore volume for the Lo, Ia, and Se soils was calculated to be 168 mL, 270 mL and 217 mL, respectively (Rowell, 1994). Each leaching event comprised of drip flow from the top onto the columns according to the hydraulic properties of each soil which gave a flow rate of 6.4–6.5, 5.1–5.8 and 1.0–1.1 cm h$^{-1}$ for the Lo, Ia and Se soils columns, respectively.

The columns were leached with 16 pore volumes (PV) over a period of 21 weeks between temperatures ranging from 18 to 26 °C in the laboratory. Initially leaching was carried out weekly (PV 1–11); then at 2 weekly intervals (PV 12–15) with a 3 week interval to the final PV. Leachate samples from each leaching event were collected and analysed as described in Section 2.2 immediately for $NH_4^+$–N, $NO_3^-$–N, pH and EC. An aliquot of about 100 mL was taken and acidified with nitric acid for determination of Ca, Mg, Na, P and K by ICP-ES. A chemical balance of inorganic-N (as $NH_4^+$–N and $NO_3^-$–N), P, K, Ca, Mg and total C was carried-out at the end of leaching based on their input and output concentrations. Leachate parameters were subjected to ANOVA for repeated measurements using Genstat 12.1. The results will be discussed with emphasis on trends and patterns of leaching.

## 3. Results and discussion

### 3.1. Soil and wastewater properties

The three soils differed in a number of important aspects especially texture, organic carbon content and base status (Table 1). The Ia is a highly weathered soil dominated in the clay fraction by kaolin, gibbsite and goethite and has very high organic carbon. The Lo is composed of mostly kaolin and quartz, indicating a chemically non-reactive soil. The Se is dominated by interstratified clay mineralogy, predominantly vermiculite, mica, chlorite and illite, suggesting a higher sorptive capacity than the other soils.

From an agricultural perspective this study considers use of ABR effluent in a worst-case scenario i.e., no dilution with other irrigation water or rainfall, as occurs in the dry season where there is no