# Nutrient distribution in three contrasting soils after anaerobic baffled reactor effluent application: A soil column study

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## Abstract

The increasing need for wastewater reuse resulted in this study to investigate the effects of effluent from an anaerobic baffled reactor (ABR) on some chemical properties of three contrasting soils after effluent leaching and the implications for peri-urban agriculture. Soil columns were leached with ABR effluent or distilled water using 16 pore volumes after which the columns were sectioned into two cm layers. The 0-2 cm, 8-10 cm and 14-16 cm layers were analysed for inorganic-N, P and K. For all soils the nutrient content, especially P, of the 0-2 cm layer was significantly ($p<0.05$) higher than the middle and bottom sections of the columns. There were significant differences between the effluent and the water-leached soils in terms of P accumulation. The amount of inorganic-N and K in the top layer was not significantly different from the other layers with the exception of the 0-2 cm layer in the Sepane soil leached with effluent.

## Key Words

Sewage effluent, soluble nutrient movement, laboratory column study, small-scale agriculture.

## Introduction

In arid and semi-arid regions the demand for freshwater is gradually increasing as good quality water has become scarce. The volume of wastewater produced is likely to increase with the growing population resulting in a need for reuse options. There is potential for the inorganic nutrients present in wastewater to be used for fertigation. The anaerobic baffled reactor (ABR) effluent is an example of such a wastewater that may be used for agricultural purposes thereby reducing the pressure on freshwater sources for irrigation, while also supplying nutrients for plant growth. Soils are often able to serve as a reservoir for wastewater because of their ability to buffer and assimilate the water, nutrients and any contaminants (Bond 1998). The ABR is a high rate anaerobic digester consisting of alternate hanging and standing baffles designed to treat wastewater (Foxon *et al.* 2004). The objective of this study was to evaluate the distribution of some plant nutrients in soil after leaching with ABR effluent, with a view to its use for irrigation in small-scale, peri-urban agriculture.

## Materials and methods

Columns consisted of polyvinyl chloride tubes, 20 cm long (i.d. = 5.3 cm). The base of each column was fitted with a perforated perspex disc (holes of 0.8 cm diameter) of the same diameter as the column and covered with nylon mesh. Glass-fibre mesh was placed on the disc before filling the column to minimise soil loss from the column during leaching. Soils were air-dried, ground to pass a 2 mm sieve and analysed following methods of The Non-Affiliated Soil Analysis Work Committee (1990). The columns were filled with the respective soils namely Longlands E horizon (Lo; Typic Plinthaquult), Inanda A (Ia; Rhodic Hapludox) and Sepane A (Se; Aquic Haplustalf) (Soil Classification Working Group 1991; Soil Survey Staff 2003) to a height of about 17 cm by uniform tapping on the bench top to achieve a bulk density of 1.48 g/cm$^3$ for the Lo, 0.75 g/cm$^3$ for the Ia and 1.12 g/cm$^3$ for the Se soil. Glass-fibre mesh was placed on the soil surface to minimise soil disturbance during the leaching procedure. The soils were leached with either ABR effluent or distilled water in triplicate (total of 18 columns). Prior to leaching the columns were saturated with distilled water by capillary flooding. With an assumed particle density of 2.65 g/cm$^3$, a pore volume for the Lo, Ia and Se soils was calculated to be 168, 270 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 cm/hr for the Lo, 5.1 - 5.8 cm/hr for the Ia and 1.0 -1.1 cm/hr for the Se. The columns were leached with 16 pore volumes over a period of 138 days corresponding to 1218 mm, 1957 mm and 1573 mm of water for the Lo, Ia and Se, respectively.

After leaching, the columns were allowed to drain, the soil was pushed out and cut into 2 cm sections. Soil samples from the 0-2, 8-10 and 14-16 cm sections were taken to represent the top, middle and bottom layers of the column and were analysed for nitrate-N and ammonium-N (Tan 1995) and soluble P and K (Rauret *et al.* 1999). The chemical composition of the ABR effluent was analysed similarly and the *E. coli* composition by plating dilutions from the column on eosin methylene blue (EMB) agar plates and counting colonies formed after incubation at 35°C for 48 hrs. Data were analysed using Genstat 12th edition and mean comparisons by Tukey's test at the 5% level.

## Results and discussion

*Soil and effluent properties*

The chemical analyses and particle size distribution of the soils are given in Table 1. The ABR effluent contains considerable amounts of plant nutrients and low concentrations of heavy metals with most being below permissible limits (Table 2). As such the effluent meets the criteria for use as an irrigation source (Ayers and Westcott 1985; DWAF 1996). The effluent belongs to salinity class C2S1 (medium salinity water/low sodicity water) and thus can be used with little risk of developing sodic conditions (United States Salinity Laboratory Staff 1954). As expected, the distilled water supplied very little nutrient input to the soil.

**Table 1. Some chemical properties and particle size distribution of the three soils.**

| | | Soil form* and horizon | | |
|---|---|---|---|---|
| Parameter | | Longlands E | Inanda A | Sepane A |
| pH | ( $H_20$) | 6.05 | 4.30 | 5.80 |
| | (1M KCl) | 4.90 | 4.00 | 4.81 |
| Electrical conductivity (dS/m) | | 0.04 | 0.05 | 0.15 |
| Organic C (g/100g) | | 0.14 | 9.60 | 3.65 |
| Total N (mg/kg) | | 533 | 5121 | 3036 |
| Extractable base cations ($cmol_c$/kg) | Ca | 2.06 | 0.85 | 10.83 |
| | Mg | 0.62 | 0.20 | 9.13 |
| | K | 0.10 | 0.17 | 0.25 |
| Exchangeable acidity ($cmol_c$/kg) | | 0.03 | 4.71 | 0.09 |
| Extractable metal cations (mg/kg) | Mn | 23.7 | 16.0 | 28.57 |
| | Cu | 2.23 | 4.40 | 2.50 |
| | Zn | 1.76 | 2.00 | 0.09 |
| Extractable P (mg/kg) | | 4.05 | 20.0 | 1.79 |
| **Particle size (%)** | | | | |
| Sand (0.053-2 mm) | | 76.6 | 35.9 | 24 |
| Silt (0.002-0.053 mm) | | 12.8 | 42.2 | 42.0 |
| Clay (<0.002 mm) | | 10.6 | 21.9 | 34.0 |

* Soil Classification Working Group (1991)

**Table 2. Chemical and *Escherichia coli* (*E. coli*) composition of the ABR effluent and distilled water.**

| | EC (dS/m) | pH | $NH_4^+$ | $NO_3^-$ | Total P | K | Ca | Mg | Na | Cr | Cu | Zn | *E. coli* (cfu/ml) | SAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (mg/L) | | | | | | | | | | | |
| Effluent | 0.641 | 7.6 | 14.3 | bd | 25.2 | 8.6 | 18.9 | 26.3 | 32.5 | 0.01 | bd | bd | $7.5*10^4$ | 1.13 |
| Distilled water | 0.003 | 6.24 | bd | bd | bd | 0.14 | 0.37 | bd | 0.3 | 0.01 | bd | 0.003 | bd | 0.14 |

*Soil nutrient retention*

The N, P and K concentrations in the leaching solutions are given in Table 3. This shows that the effluent added to the content of these elements in soil unlike the distilled water that leached most of the elements, as indicated by the negative values.

There were no significant differences ($p<0.05$) in the inorganic-N between the soil layers from both the water and effluent-leached columns with levels below detection recorded for all Lo samples and Se (0-2 cm) in the water-leached columns (Table 4). This could be attributed to the high percolation of nitrate–N and the conversion of ammonium-N to nitrate-N as shown by Egiarte *et al.* (2006) when using an anaerobic municipal sludge in an acid soil.

There were marked differences between the P concentrations in the soil layers for the effluent and water-leached columns (Table 4). In all soils, the 0-2 cm layer had a significantly ($p<0.05$) higher concentration of P than the middle and bottom layers. This build-up, although less in the Lo than in the Ia and Se soils, suggest P is bound in soil by organic and/or inorganic constituents. The specific adsorption capacity of soils to retain P can contribute to prevent its movement in soil. Microbial immobilization could be a further reason for this occurrence, especially in the sandy Lo soil (Janssen *et al.* 2005).

For K, the Ia and the Se (0-2 cm) showed significant differences between the effluent and water-leached columns. The trend in the Lo was similar for K and inorganic-N which may be as a result of the smaller contribution from the effluent when compared with P.

**Table 3. Quantity of inorganic-N (In-N), P and K retained in the soils from the leaching solutions.**

| Nutrient | Longlands E | | Inanda A | | Sepane A | |
|---|---|---|---|---|---|---|
| (mg/kg) | effluent | water | effluent | water | effluent | water |
| In-N | 7.9 | -17.7* | 72.4 | -168.2 | 60.9 | -22.6 |
| P | 115.2 | 0.02 | 367.3 | 0.17 | 191.4 | 0.1 |
| K | 24 | -6.6 | 18.8 | -38.9 | 72.3 | -4.2 |

* negative values indicate amount lost from soil

**Table 4. Mean values of soluble inorganic-N (In-N), P and K (mg/kg) for column layers after leaching.**

| Soil depth(cm) | Soil form* | Leaching solution | | | | | |
|---|---|---|---|---|---|---|---|
| | | Distilled water | | | Effluent | | |
| | | In-N | P | K | In-N | P | K |
| 0-2 | Lo | **bd**** | 5.0a[#] | 22.7a | 2.0ab | 102.5bc | 43.2abc |
| | Ia | 26.1bcd | 2.3a | 45.5abc | 30.0cd | 98.4b | 164.0gh |
| | Se | **bd** | 2.7a | 70.2bcde | 6.7abc | 186.5d | 172.7h |
| 8-10 | Lo | **bd** | 3.5a | 21.9a | 1.4a | 46.9a | 41.5abc |
| | Ia | 28.3cd | 2.4a | 54.2abc | 49.8d | 1.9a | 130.6fg |
| | Se | 8.3abc | 1.1a | 81.8cde | 0.6a | 12.0a | 96.6def |
| 14-16 | Lo | **bd** | 2.6a | 22.8a | 2.5ab | 9.6a | 37.4ab |
| | Ia | 17.5abc | 2.3a | 63.2abcd | 30.2cd | 2.6a | 112.2ef |
| | Se | 13.9abc | 2.3a | 83.6cde | 1.6ab | 2.6a | 99.9def |

* Soil Classification Working Group (1991)

[#] Values in each column followed by the same letter are not significantly different ($p<0.05$)

** **bd** below detection

## Conclusion

The accumulation of nutrients especially P in the top soil layer during leaching was influenced by the nutrient loading in the effluent giving an opportunity for uptake by plants and also reducing the risk of downward movement of high risk elements such as P into groundwater. It would appear that the ABR effluent has potential for use in fertigation. There are various mechanisms that control the migration and retention of P in effluent-irrigated soils thus necessitating long-term studies. Inorganic-N and K leaching was not as significant between the soil layers.

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