Nutrient availability from anaerobic baffled reactor effluent for maize growth in three contrasting soils from KwaZulu-Natal, South Africa

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Abstract

This study was undertaken to assess the availability to maize of nutrients in effluent from an anaerobic baffled reactor (ABR) for use in peri-urban agriculture. Maize was grown in pots filled with three contrasting soils with fertilizer (N, P and K) applied at the full recommended rate, half the recommended rate and no fertilizer. Plants were watered with either ABR effluent or tap water. After 6 weeks plants were harvested and above-ground dry matter yield and nutrient concentrations were measured. Dry matter yield and nutrient concentrations for effluent-irrigated maize were significantly higher for all fertilizer applications ($p<0.05$) than the water-irrigated plants. The unfertilized effluent-irrigated plants were not significantly different from the fertilized water-irrigated plants, but performed as well as the water-irrigated plants at half fertilization irrespective of soil type. Phosphorus deficiency was shown in the two heavier textured soils but not in the sandy soil irrespective of fertilizer treatment.

Keywords

Sewage effluent, plant nutrients, soil type, maize yield, small-scale agriculture

Introduction

Treated sewage effluent has been successfully used for crop irrigation in several countries (Feigin *et al.* 1991; Fonseca *et al.* 2007). The anaerobic baffled reactor (ABR) is a high rate anaerobic digester consisting of alternate hanging and standing baffles designed to treat wastewater (Foxon *et al.* 2004). Foxon *et al.* (2005) conducted a small-scale field study on the use of ABR effluent on plant growth and results were comparable with irrigating using a commercial plant nutrient solution. The objectives of this study were 1) to investigate the potential of ABR effluent as a nutrient source for plants (in particular N, P and K) and 2) to assess the potential of the ABR effluent as an irrigation source for small-scale, peri-urban agriculture in South Africa.

Materials and methods

A pot experiment was carried out in a glasshouse at the University of KwaZulu-Natal (UKZN), Pietermaritzburg with maximum and minimum temperatures of 26°C and 16°C, respectively. Three contrasting soil types were used namely a Cartref E horizon (Cf; Typic Haplaquept), Inanda A (Ia; Rhodic Hapludox) and Sepane A (Se; Aquic Haplustalf) (Soil Classification Working Group 1991; Soil Survey Staff 2003). Soils were air dried, ground to pass a 2 mm sieve and physico-chemical properties determined following methods of The Non Affiliated Soil Analysis Work Committee (1990). Pots (i.d. = 20 cm) were filled with 2 kg soil and N, P and K fertilizer was applied at the full recommended rate for a soil type, half the recommended rate and no fertilizer. Ammonium nitrate, potassium dihydrogen phosphate and potassium nitrate were used to supply the fertilizer nutrients in solution before planting at different rates (0, 100, 200 kg N/ha for all soils; 0, 40, 80 kg P/ha and 0, 50, 100 kg K/ha for the Cf; 0, 10, 20 kg P/ha and 0, 102.5, 205 kg K/ha for Ia; and 0, 30, 60 kg P/ha and 0, 5, 10 kg K/ha for Se). Pots were watered with either ABR effluent or tap water. The ABR effluent was sourced from a pilot plant in the School of Chemical Engineering, UKZN, Durban. Each treatment was run in triplicate (total of 54 pots) and the experiment was laid out in a randomized complete block design. Lime (calcium hydroxide) was applied to all Ia treatments at the rate of 10 t/ha and eight maize seeds (PAN 4P-767BR) were planted per pot and thinned to four plants two weeks after planting. Plants were watered according to evapotranspiration demands and the total volume of solution added was equivalent to 43.3, 82.7 and 52.6 mm of rainfall for the Cf, Ia and Se, respectively.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

After six weeks growth, plant height and number of leaves were measured. The plants were harvested at 1 cm above soil level, and dried at 70 °C to determine dry matter yield. Dried samples were ground and stored for plant nutrient analyses. Nitrogen was determined by Kjeldahl digestion (Rowell 1994). Phosphorus and K were determined by inductively coupled plasma optical emission spectrometry after nitric acid digestion. Data were analysed using Genstat 12th edition and the Student Newman Keul range test at 5% was used to determine differences between treatment means. The chemical composition of the ABR effluent was analysed by inductively coupled plasma optical emission spectrometry 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.

Results and discussion

Soil and effluent characterization

The chemical analyses and particle size distribution of the soils are given in Table 1.

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

		Soil form* and horizon		
Parameter		Cartref E	Inanda A	Sepane A
pH	(H_20)	6.24	4.44	7.09
	(1M KCl)	4.62	3.97	5.61
Electrical conductivity (dS/m)		0.017	0.089	0.097
Organic C (g/100g)		0.18	7.54	1.92
Total N (mg/kg)		352	6234	2087
Extractable base cations ($cmol_c$/kg)	Ca	1.1	0.6	8.2
	Mg	0.4	0.2	7.4
	K	0.1	0.1	0.3
Exchangeable acidity ($cmol_c$/kg)		0.06	4.31	0.08
Extractable metal cations (mg/kg)	Mn	3.5	6.5	9.6
	Cu	0.7	1.9	2.6
	Zn	0.1	0.8	4.3
Extractable P (mg/kg)		2.1	15.6	5.2
Particle size (%)				
Sand (0.053-2 mm)		80.2	29.9	21.4
Silt (0.002-0.053 mm)		12.9	48.2	42.9
Clay (<0.002 mm)		6.9	21.9	35.7

* Soil Classification Working Group (1991)

The effluent had low heavy metal concentrations (Table 2) which were below the Food and Agricultural Organization critical limits for irrigation (Ayers and Westcott 1985). This was attributed to the fact that the effluent is derived from a domestic source. The low SAR and EC of the effluent places it in a class with no restrictions for use in irrigation (C2S1; United States Salinity Laboratory Staff 1954). The total amount of N, P and K supplied by the effluent and the water during the course of the pot experiment is given in Table 3.

Dry matter yield and nutrient accumulation

There was a significant ($p<0.05$) difference in dry matter yield between plants watered with the different irrigating solutions irrespective of fertilizer applied (Table 4). The only exception was in the unfertilized, effluent-irrigated plants which were not significantly different from the fertilized treatments irrigated with water. This trend also applied irrespective of soil type indicating the potential that the effluent has to enhance plant growth. The Cf at full fertilizer rate and irrigated with effluent had the highest dry matter yield (4900 mg/pot).

The maize nutrient content was significantly higher ($p<0.05$) in the effluent-irrigated soils than in the water-irrigated soils. Comparisons between the fully fertilized plants showed that the effluent-irrigated plants were significantly different from the water-irrigated plants indicating an additional input from the effluent. These results are in agreement with the observations of Bielorai *et al.* (1984) but contrary to those of Fonseca *et al.*

Table 2. Chemical and *E.coli* composition of the ABR effluent and tap water.

	EC (dS/m)	pH	Total N	Total P	K	Ca	Mg	Na	Cr	Cu	Zn	*E. coli* (cfu/ml)	SAR
			(mg/L)										
Effluent	0.497	6.68	9.7	30.4	10.5	16.1	18.7	27.2	0.01	0.04	0.04	$2.2*10^2$	0.59
Tap water	0.104	6.62	1.3	0.01	3.5	6.8	2.2	3.5	0.01	0.06	0.84	bd	0.18

bd below detection

Table 3. Total amounts of N, P, and K supplied by the irrigation solutions.

Nutrient (kg/ha)	Cartref		Inanda		Sepane	
	effluent	water	effluent	water	effluent	water
N	65	8	40	5	47	6.5
P	200	0.1	123	0.1	146	0.1
K	70	22	42.5	14	50.3	17

Table 4. Effects of irrigation source and fertilization on mean dry matter yields and nutrient concentration (n =3) in above-ground biomass of maize.

Irrigation solution	Fertilizer rate	Soil form*	Dry matter yield (mg/pot)	Above ground nutrient concentration (mg/pot)		
				N	P	K
Effluent	Full	Cf	4900.0j[#]	80.2g	12.7g	55.6fg
		Ia	3300.0gh	81.0g	3.3d	83.2h
		Se	2766.7fg	55.7e	2.8cd	47.4ef
	Half	Cf	3733.3hi	59.5e	10.2f	44.9de
		Ia	2833.3fg	66.7f	2.3bc	52.7ef
		Se	2533.3ef	25.8b	2.4c	44.1de
	Zero	Cf	2266.7def	31.9bc	5.2e	33.8bc
		Ia	2166.7cdef	47.2d	2.1abc	32.1bc
		Se	2133.3bcdef	37.2c	1.9abc	34.5bc
Water	Full	Cf	3233.3gh	57.1e	4.7e	53.3ef
		Ia	1766.7abcde	45.8d	1.2a	48.8ef
		Se	1566.7abcd	19.1a	1.2a	31.7bc
	Half	Cf	2400.0ef	32.7bc	2.4c	37.5cd
		Ia	1333.3ab	37.5c	1.03a	27.5bc
		Se	1866.7abcde	26.8b	1.4ab	37.3cd
	Zero	Cf	1333.3ab	14.5a	1.0a	25.7b
		Ia	1400.0abc	34.0bc	1.1a	19.2a
		Se	1233.3a	12.6a	1.3a	31.5bc

* Cf = Cartref; Ia = Inanda; Se = Sepane

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

(2005) who reported that the use of secondary treated sewage effluent on adequately fertilized maize plants did not increase plant N content. Phosphorus deficiency was evident in all treatments on the Ia and Se soils and was more severe in the water-irrigated than in the effluent-irrigated pots but did not occur in the Cf soil treatments. Despite this trend, the P content in the effluent-irrigated plants was higher than in the water-irrigated plants, irrespective of fertilizer use. This is likely due to the high sand content of the Cf soil, resulting in low cation and anion holding capacities allowing maximum absorption by plants and resulting in vigorous growth and high water demand. The P deficiency in the Ia and Se soils was probably due to its non-availability to plant roots due to higher amounts of iron and aluminum oxides in these soils. Plant K content was also higher in the fertilized effluent-irrigated treatments than in the water-irrigated treatments with Ia having the highest value.

Conclusion

The ABR effluent used to irrigate maize improved dry matter yields and nutrient concentrations when compared with similar treatments irrigated with water. However, the unfertilized effluent-irrigated plants were not significantly different from the water-irrigated plants with half the recommended fertilizer rate. This suggests that the effluent can supplement fertilizer use for maize thus reducing costs for small-scale peri-urban farmers.

Acknowledgements

We are grateful to the eThekwini Municipality, Durban, South Africa for funding this research and the Soil Fertility and Analytical Services Division (KwaZulu-Natal Department of Agriculture, Cedara) for some of the analyses.

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