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The effect of irrigation with anaerobic baffled reactor effluent on nutrient availability, soil properties and maize growth

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ABSTRACT

A glasshouse study was carried out to assess the availability to maize of nutrients from anaerobic baffled reactor (ABR) effluent. Maize was grown for 6 weeks in pots with three contrasting soils namely a sandy soil (Cartref (Cf), Typic Haplaquept), an organic, acidic soil (Inanda (Ia), Rhodic Hapludox) and a clayey soil (Sepane (Se), Aquic Haplustalf). Fertilizer (N, P and K) was applied at the recommended rate, half the recommended rate and zero fertilizer for each of the soils used. Lime was applied to the Ia following recommendations. Plants were irrigated with either effluent or tap water. Dry matter yields and nutrient concentrations for effluent-irrigated maize were significantly higher ($p < 0.05$) than for all water-irrigated plants. For each soil, the unfertilized, effluent-irrigated plants were not significantly different in most of the above-ground nutrient concentrations from the water-irrigated plants at half fertilization. Phosphorus deficiency was observed in the Ia and Se but not in the Cf, irrespective of fertilizer treatment. Plants grown on the Cf irrigated with effluent and fully fertilized had the highest above-ground dry matter yield (4.90 g pot^{-1}) and accumulated more N, P, K, Ca and Mg than all other treatments. After harvest, P in the Cf soil was significantly higher ($p < 0.05$) in the effluent-irrigated than the water-irrigated soils reflecting P input from the effluent. Concurrently, the effect of the effluent was further investigated by planting maize on the Ia with neither lime application nor fertilization. Plants that received effluent irrigation and no lime had significantly higher ($p < 0.05$) dry matter yields (2.67 g pot^{-1}) and accumulated more N, P and K than those water-irrigated with no lime as well as the equivalent limed treatments. This suggests an interaction effect between the lime and effluent properties.

1. Introduction

Treated sewage effluent has been used for crop irrigation in several countries (Feigin et al., 1991; Chen et al., 2004; Fonseca et al., 2007). Soil application of treated wastewater as a water and nutrient source for agricultural irrigation represents a low cost alternative for wastewater treatment (Asano et al., 1996; Cameron et al., 1997). The application of treated wastewater to the soil–plant system may mitigate the scarcity of water resources and reduce the discharge of nutrients to water bodies by using soil and plants as natural filters (Pollice et al., 2004). Thus, crop irrigation with treated wastewater constitutes an ecologically sound method for the disposal of effluent into the environment (Toze, 2006). The ability of soil to retain nutrients from treated sewage effluent (Stewart et al., 1990; Fonseca et al., 2005b) suggests the possibility that such nutrients can be used for crop growth (Al-Jaloud et al., 1995; Mohammad and Mazahreh, 2003). The concentrations of ions in soils are influenced by water movement, their concentrations in irrigation water, soil properties and plant uptake (Heidarpour et al., 2007). Understanding how these components interact and influence nutrient availability for plant growth requires studies that consider all these components.

In South Africa existing guidelines for wastewater use have focused mainly on the potential harmful effects of heavy metals in water (Department of Water Affairs and Forestry (DWAF), 1996) and have not considered the potential benefits of using nutrient-rich effluent from low cost sanitation technologies for irrigation purposes. In addition, these guidelines do not allow for the soil's contribution in reducing the problems associated with effluent utilisation, which has resulted in unduly restrictive measures that cannot be adequately enforced.

The anaerobic baffled reactor (ABR) is a high rate, anaerobic digester consisting of alternate hanging and standing baffles designed to treat wastewater. The design of the ABR has undergone improvement over many years to make it suitable for treating a wide variety of wastewater sources (Barber and Stuckey, 1999). Studies by Foxon et al. (2005) have shown that an ABR treating domestic wastewater will convert a large amount of wastewater

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chemical oxygen demand to methane gas which is currently vented to the atmosphere although further development of the reactor is underway so that the methane is captured, reduce pathogen loads in the wastewater effluent, but still leave considerable amounts of ammonium and phosphates in the effluent, which is thus unsuitable for discharge to surface and groundwater bodies. However, the nutrients in the effluent have economic value as a fertilizer where it has potential to be used for agricultural irrigation purposes (Foxon et al., 2004). Because such communal ABRs receive input from purely domestic sources the likelihood of heavy metals is very low, unlike wastewater from many sewage treatment plants, making ABR wastewater a very promising source of agricultural irrigation. Elements such as Ca and Mg needed for plant growth can accumulate in soils thereby improving the pH especially of acidic soils (Lourenzi et al., 2011). Since the ABR effluent contains a range of plant nutrients its use would be more strictly termed ‘fertigation’ as opposed to ‘irrigation’. However, in this paper, for ease of reference to the different treatments applied, the term “effluent-irrigated” is used since fertigation could imply that no supplementary fertilizers were used. There is need, therefore, to assess the benefits to agriculture of effluent application relative to inorganic fertilizer application, which is widely used to boost agricultural production. Addressing sanitation concerns through low cost technologies could contribute to the provision of both water and nutrients for agriculture. This study focuses on the role of soil in the conversion of a waste product (ABR effluent) from housing developments into an agricultural resource. Thus the objectives of this study were to: (i) investigate the potential of ABR effluent for crop growth; (ii) assess nutrient accumulation in plants (in particular N, P, K, Ca and Mg) from use of the effluent; (iii) assess residual effects of plant nutrients in soil after effluent application; and (iv) investigate the liming capability of the effluent.

2. Materials and methods

2.1. Soil collection and characterization

Three contrasting soil types were used namely a Cartref E horizon (Cf; Typic Haplaquept), and the A horizons of an Inanda (Ia; Rhodic Hapludox) and Sepane (Se; Aquic Haplustalf) (Soil Classification Working Group, 1991; Soil Survey Staff, 2010). The Ia was collected from World’s View, Pietermaritzburg under commercial pine forestry, the Cf from Ottos Bluff near Pietermaritzburg under virgin veld and the Se from a permaculture site at Newlands-Mashu, near Durban. These 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). The clay mineralogy of the three soils was estimated qualitatively using X-ray diffraction. Clay separated from each soil was saturated with either Mg or K, prepared as smear specimens on glass slides and run on a Philips PW1050 diffractometer using monochromated CoKα radiation from 3 to 40° 2Θ at 1° per minute scan speed with a 0.02° counting interval. Data were collected automatically by a Sietronics 122 micro-processor coupled to the diffractometer.

2.2. Anaerobic baffled reactor (ABR) effluent

The effluent was sourced from a pilot plant at the School of Chemical Engineering, University of KwaZulu-Natal (UKZN), Durban, South Africa, which was fed manually and produced about 100 L of effluent in 24 h. The effluent was collected and stored at 4 °C in the Soil Science laboratory at UKZN, Pietermaritzburg Campus where the research was conducted. The pH and electrical conductivity (EC) of the ABR effluent were measured on a Radiometer PHM 210 meter and a CDM 210 electrical conductivity metre with temperature correction for 25 °C, respectively. The $NH_4{}^+$-N and $NO_3{}^-$-N were analysed with a TRAACS 2000 continuous flow auto-analyser. Total N was determined by steam distillation with magnesium oxide and Devarda’s alloy (Rowell, 1994). Total carbon was measured with a Shidmadzu TOC-V CPN analyser. Major and minor elements as well as heavy metals in the unfiltered effluent were analysed by inductively coupled plasma emission spectrometry (ICP, Varian 720-ES). Prior to its use for irrigation the required estimated quantity of effluent was removed from cold storage and allowed to equilibrate to room temperature.

2.3. Pot experiment 1

A pot experiment was carried out in a glasshouse at UKZN, Pietermaritzburg with recorded maximum and minimum temperatures of 26 and 16 °C, respectively. Pots with inner diameter of 20 cm and height of 17 cm were filled with 2 kg soil to approximate field bulk densities of 1.47, 0.77 and 1.21 g cm^{-3} for Cf, Ia and Se soils, respectively, measured by the method of Tan (1996). Fertilizer (N, P and K) was applied at the rates recommended by the KwaZulu-Natal Department of Agriculture Soil and Analytical Services Laboratory after soil fertility testing using proprietary software developed by the laboratory for local conditions and the test procedures they use. The P and K analyses are based on soil test values derived from ammonium bicarbonate extraction, while N recommendations are blanket rates based on local conditions and the N requirements for maize production in the KwaZulu-Natal region. The fertilizer recommendations are received as a rate per hectare application and these were converted to a mass basis by adjusting the rate using the soil bulk densities and assuming a soil depth of 30 cm. In addition to the recommended N, P and K rates the fertilizers were also applied at half the recommended rate. An unfertilized control was also included for each soil (rate 0). Laboratory grade ammonium nitrate, potassium dihydrogen phosphate and potassium nitrate were used to supply the fertilizer nutrients in solution at different rates before planting (0, 100, 200 kg N ha^{-1} for all soils; 0, 40, 80 kg P ha^{-1} and 0, 50, 100 kg K ha^{-1} for the Cf; 0, 10, 20 kg P ha^{-1} and 0, 102.5, 205 kg K ha^{-1} for Ia; and 0, 30, 60 kg P $ha^{-1}$and 0, 5, 10 kg K ha^{-1} for Se). This was halved for the half fertilizer rate and no fertilizer was applied for the zero fertilizer rate. All pots were treated with a 5 mL aliquot of sodium molybdate (Na_2MoO_4) irrespective of fertilizer rate and irrigation solution to supply molybdenum. Magnesium sulphate ($MgSO_4{\cdot}7H_2O$) was used to supplement the Mg requirements of the Ia soil following recommendations. Lime recommendation (as supplied by the KwaZulu-Natal Department of Agriculture Soil and Analytical Services Laboratory) for the Ia at 10 t ha^{-1} was applied to all pots as pure grade $Ca(OH)_2$ in order to achieve a faster liming effect compared to commercial grade lime considering the growth duration of the experiment. Eight maize seeds (PAN 4P-767BR) were planted per pot and later thinned to four plants 2 weeks after planting by uprooting. Pots were irrigated with either potable (tap) water or ABR effluent. Each treatment was applied in triplicate (total of 54 pots) and the experiment was laid out in a randomized complete block design generated by Genstat 12th edition (Payne et al., 2009). At the initiation of the experiment the pots were wet to 70% field capacity. Subsequently pots were watered periodically to prevent drought stress in the maize plants. Rather than attempt to accurately control the moisture content of the pots and nutrients applied through watering, the volume of either the effluent or water applied was recorded at each watering event. Any leachate from the pots was returned to the soil surface giving a closed watering system. The amount of nutrient applied with each watering event was then determined from the previously determined nutrient contents of the effluent and water used. At the end of the experiment the total