NUTRIENT UPTAKE AND LEACHING AFTER IRRIGATING TARO (*COLACASIA ESCULENTUM*) AND BANANA (*MUSA ACUMINATA*) WITH DEWATS EFFLUENT.

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ABSTRACT

The Decentralised Wastewater Treatment System (DEWATS) provide an alternative sanitation solution to residents living in informal settlements. The disposal of treated wastewater in rivers can cause pollution hence agricultural systems may remove nutrients and water from treated effluent, allowing less polluted water to flow deeper in the soil. A field study was conducted, aiming to investigate nutrient uptake and leaching in banana and taro intercrop irrigated with DEWATS effluent (After horizontal flow gravel filter treatment). An experiment was conducted in a randomised complete block design (RCBD) with two treatments (DEWATS effluent irrigation; DW and Tap water irrigation + fertiliser; TWF). Crop nutrient (N and P) uptake and leaching after irrigation with DEWATS effluent was comparable to other conventional agricultural practices. A banana and taro intercrop may be a potential option for treating wastewater in a way that is beneficial to peri urban communities.

Keywords: banana, DEWATS, leaching, nutrient uptake, taro.

INTRODUCTION

The provision of onsite sanitation to residents living in informal settlements of South Africa, where centralised wastewater treatment systems can hardly be connected is one of the major aims of local governments in South Africa . The Decentralised Wastewater Treatment System (DEWATS) is a potential option since it is cheap to operate due to low energy requirements. The DEWATS is comprised of an Anaerobic Baffled Reactor (ABR), which degrade blackwater and greywater to produce biogas and treated wastewater. The disposal of treated wastewater is of both environmental and health concern[9]. High microbial and nutrient loads from the ABR effluent prohibits its disposal into water bodies. Furthermore, the presence of total solids is of agricultural concern since they clog irrigation systems. To meet standards required for discharge into water bodies further treatments that reduce its nutrient loads are required and constructed wetlands might be important. [1]

After the ABR treatment, DEWATS effluent passes through gravel filters for further treatment. There are two types of gravel filters (Vertical Flow Gravel Filters; VFGF and the Horizontal Flow Gravel Filters; HFGF) [24]. The VFGF is the first filter after the ABR where water passes vertically into the gravel filters and then moves onto the HFGF, which filters it horizontally. As the water passes through the gravel filters nutrients are lost through a series of nutrient transformations. Ammonium-N undergoes nitrification to produce nitrate-N and this is taken up by plants in the system [26]. During the process solids are also removed and most pathogens are killed [15] hence its use for agriculture can be safer. Wetlands cannot remove all the nutrients after treatment hence the disposal of treated effluent must be carefully done. A well-functioning wastewater treatment system must be able to remove all contaminants before the water can reach rivers and underground water resources. Agricultural use of treated wastewater as a soil disposal method is widely recommended [8]. Irrigation of crops with treated wastewater is important for the recycling of nutrients than to discharge into rivers [17]. This creates a system whereby soils act as media for nutrient retention and allowing subsequent uptake by crops[2] . The amount of total nitrogen removal by banana is related to the amount of biomass produced and they have a total removal of 278 kg ha^{-1} of N per plant [13]. However, a taro and banana intercrop may potentially increase the efficiency of nutrient and water removal within the system, thereby leaving less water and nutrients leaching below the root zone and laterally to nearby rivers.

Different factors (pH, temperatures, texture and microorganisms) affect nitrogen and phosphorus transformations in the soil. Conversion of ammonium-N to nitrate-N occurs through the process called nitrification and this is faster at optimum pH (6.6-8), presence of oxygen, and optimum temperatures of 30 - 35 ^{o}C [16]. Nitrates have a negative charge hence they dissolve in soil solution where they easily leach down the soil profile, polluting groundwater resources [11]. Nutrient leaching results from by different factors such as irrigation management practices, rainfall, fertigation water quality and the soil physical properties [16].

Several studies conducted reported treated wastewater to increased crop growth, nutrient uptake; improve soil chemical and physical properties [3]. Studies reported insignificant movement of nitrates and phosphates from root zone to below root zone under a vegetable crop [19]. John and McConchie (1994)[14] studied the effects of secondary treated effluent on banana crop and found out it could provide adequate nutrients for banana growth without effects on the environment. However, there is no information on nutrient uptake and leaching after irrigating taro and banana crops (long season crops) in an intercrop. The study investigated the effects of DEWATS effluent (after HGF treatment) on (i) nutrient uptake and growth of banana and taro intercrop (ii) soil chemical properties at different depths (0-30 cm, 30-60 cm and 60-90 cm) (iii) N and P leaching at 30 cm and 50 cm depths under a taro and banana intercrop.

MATERIALS AND METHODS

Site description

A field experiment was conducted at Newlands Mashu Research Facility located in Durban, South Africa (30°57'E, 29°58'S); east coast (altitude 14 m above sea level). The site receives an annual rainfall of approximately 1000 mm and mean daily temperatures of 20.5° C. The soils at the site are predominately clay loam soils with about with a bulk density of between 1.25 to 1.43 g cm^{-3} (Table 1). The climate is characterised by savanna weather conditions; cool dry winters followed by hot wet summers.

Soil physical and chemical characteristics

Soil samples collected from three different layers (0-30cm, 30-60 cm and 60-90 cm) were characterised for their physical properties (Table 1). Bulk density was determined using the undisturbed soil cores, particle size analysis was done using the hydrometer method and the soil texture was classified according to USDA classification method [22].

Table 1. Newlands Mashu soil physical characteristics (texture and bulk density at three different soil depths)

Soil Depth	Soil texture			Bulk density
	Sand	Silt **%**	Clay	**(g cm^{-3})**
0 - 30 cm	18.1	46.2	35.7	1.25
30 - 60 cm	20	38.9	41.2	1.43
60 – 90 cm	21.6	35.7	42.7	1.28

Five soil samples collected randomly within each plot (70 m^2) and bulked to make a composite sample. Each composite sample from three different soil depths (0-30 cm, 30-60 cm and 60-90 cm) was analysed for chemical properties at Fertilizer Advisory Service, KZN Department of Agriculture and Environmental Affairs, Soil Fertility and Analytical Service, CEDARA. Freshly collected soil samples for ammonium-N and nitrate-N analysis from the three depths were extracted using KCl [20]. The extracts were analysed for ammonium-N and nitrate-N using the Merk spectrophotometer ® according to standard methods [6].

Trial establishment and management

A field experiment was laid out as a single factor analysis in a Randomised Complete Block Design (RCBD) with two treatments (DEWATS effluent irrigation; DW and Tap water irrigation + fertiliser; TWF) and two crops (Taro and Banana) as an intercrop. Banana seedlings (*Musa acuminate* var Williams) were purchased from Zululand Nurseries in Eshowe, KwaZulu Natal and Taro seed (Dumbe lomfula) was obtained from Ukulinga, University of KwaZulu Natal Agricultural research farm. Banana was planted at a spacing of 3 m x 1.5 m while taro was planted as an intercrop between the banana rows at a spacing of 1 m x 1 m. No fertiliser was applied to taro irrigated with tap water, however it was applied to banana plants based on soil chemical analysis results. Urea (46 % N) was applied at a rate of 34 g $matt^{-1}$ per month for a period of 8 months (280 kg ha^{-1} N) and three applications of KCl (52 % K) was done at a rate of 140 g $matt^{-1}$ (485 kg ha^{-1}) at a three months interval. Soil P levels were adequate hence P fertiliser was not applied.

Treated wastewater for irrigation was obtained from the Horizontal Flow Constructed Wetlands (HFCW), which is the second gravel filter after the Vertical Gravel Filter (VGF). Irrigation of trials was done using a Rainbird ESP-Me ® controlled drip irrigation system. The Pedrollo (Pedrollo, UK) pump was used to pump DEWATS effluent to the field at a pressure of two bars. Irrigation was done four times a day with a dispersal of two litres per plant per hour, totalling to eight litres per plant per day. Soil moisture was monitored by CS 650 soil content reflectometers (Campbell Scientific, INC.), accuracy measurement at ≤ 3 dS m^{-1} (EC) without any soil specific calibration. Reflectometers were inserted at three soil depths (0 - 30 cm, 30 – 60 cm and 60 – 90 cm) to monitor the profile moisture content. Plant water stress was monitored using the Precision Infrared Temperature sensor (IRTS-P) (Campbell Scientific, INC.).

Banana and taro growth parameters (Plant height, number of leaves, leaf length and width and chlorophyll content) were measured during the growing season. In banana plant height was measured from the base of the plant to the bottom of the third youngest mature leaf. Leaf length and width were measured on the third youngest mature leaf. Taro plant height was measured from the bottom of the plant to the apex of the second youngest leaf. Leaf area index was determined based on total leaf area per certain area. Chlorophyll content was measured using the CCM 200-plus chlorophyll meter (Optisciences, Inc.).

Characterisation of the DEWATS effluent

DEWATS effluent was collected from the Horizontal Gravel Filter (HGF) and analysed for mineral nutrients (Ammonium-N, Orthophosphate-P and Nitrate-N) using the Merk spectrophotometer ® according to standard methods for wastewater analysis [6].

Plant tissue analysis

Banana plant tissue analysis was done at flowering stage. Plant tissue samples were collected by cutting the middle section of the lamina on the third uppermost leaf. The leaves were oven dried at 60 ^{o}C for 72 hours, crushed and passed through a 1 mm sieve. Taro corms were freeze dried, crushed and passed through a 1 mm sieve and analysed for macro and micronutrients

Data analysis

All statistical analyses were done using GenStat® 14th Edition (VSN International, Hemel Hempstead, UK). Means were compared using Standard errors of deviation (SEDs) at 5% significance level.

RESULTS

Characterisation of DEWATS effluent

Table 2 shows the chemical characteristics of the DEWATS effluent (After Horizontal Planted Gravel Filter) used for irrigating crops during the study. The treated DEWATS effluent meets all the minimum standards for irrigating with 50 m^3 of treated wastewater as stated by the Department of Water Affairs regulations [5].

Table 2. Chemical properties (mineral nutrients, Chemical Oxygen Demand, pH, suspended solids and electrical conductivity) of the DEWATS effluent used during the study.

	Unit	**N sample**	**HGF**	**Discharge limit (Up to 50 m^3 per day)**	**SED**
Ammonium-N		3	6.7	**-**	1.07
Nitrate-N		3	12.73	**-**	7.86
Total mineral-N	**(mg L^{-1})**	6	19.43		
Orthophosphate-P		3	4.13	**-**	0.55
Suspended solids		19	4		1.35
pH		19	6.63	**6 – 9**	0.07
COD	**(mg L^{-1} O_2)**	19	67.95	**5000**	7.67
Conductivity	**(mS/m)**	19	74.11	**≤ 200**	2.92

N and P from DEWATS effluent

Table 3 describes the amounts of mineral nutrients (N and P) supplied by the DEWATS effluent after irrigating banana and taro based on the volumes of effluent used during the study. The effluent could provide banana plants with 71.16 and 15.13 kg ha^{-1} of N and P respectively. Taro plants received 149.43 kg ha^{-1} (N) and 31.76 kg ha^{-1} (P) from the quantities of effluent used for irrigation.

Table 3. Mineral nutrients (N and P; kg ha-1) applied to different crops (banana and taro) based on the volumes of water used for irrigation (June 2014 to April 2015).

	Taro	**Banana**
Effluent applied (L)	69216	32960
Mineral-N (mg L^{-1})	19.43	19.43
Mineral-N (kg ha^{-1})	149.43	71.16

Orthophosphate-P (mg L^{-1})	4.13	4.13
Orthophosphate-P (kg ha^{-1})	31.76	15.13

Weather data

Weather conditions (relative humidity, temperatures and rainfall) play a crucial role in crop growth and development. They contribute to transpiration rate, nutrient uptake and photosynthesis, which are drivers for optimum crop growth hence figure 1 describes weather parameters recorded on the site during the growing season. The site was characterised of high temperatures during the summer followed by low temperatures in winter season. During the summer period (October to April) up to > 40 ^{o}C maximum temperatures where recorded and there were cool minimum temperatures down to < 5 ^{o}C in winter (May to September). High reference evapotranspiration (Eto) values up to 6 mm were recorded in winter period when there was high vapour pressure deficit. South Africa is characterised by hot wet summers followed by cool dry winters, however the graphs shows high rainfall regimes (November 2013 – April 2014 and September 2014 – April 2015). These seasonal variations have effects on the growing season for banana[7].

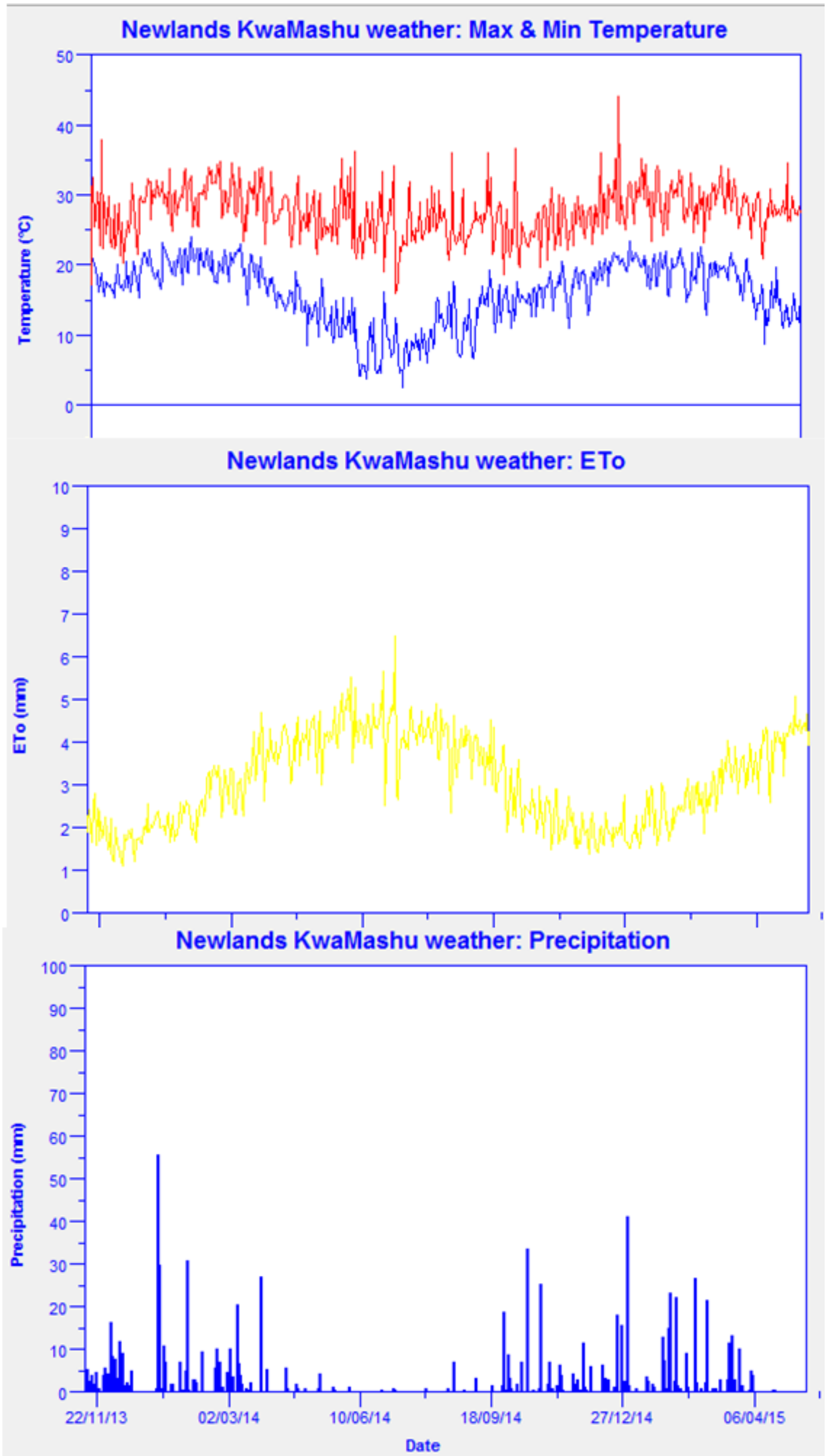

Figure 1. Weather data (Evapotranspiration, temperatures and rainfall) for the experimental site during the growing season of the two crops

Crop growth and development

Figure 2 describes the growth and development of banana and taro during their growing season. Taro growth parameters (vegetative growth index, leaf area index and plant height were all measured at six, seven and eight months after crop establishment. There was a significant response ($P < 0.05$) of taro to irrigation with DEWATS effluent at six and eight months after crop establishment. DW had higher growth parameters (vegetative growth index, plant height and leaf area index). Fertiliser was not applied to the minor crop (taro) while in the DW treatment crops received nutrients from the effluent (Table 3) hence taro in DW treatment grew faster than in TWF. Studies showed that increasing N fertiliser application rates leads to prolific vegetative growth in taro although he reported reduced harvest index following high fertiliser doses [10].

Crop growth was high during summer periods (from planting to six months after planting and nine to 12 months after planting) due to high temperatures and rainfall (Figure 1). Bananas are tropical crops, which needs high temperatures for growth [7]. Results shows a significantly higher ($P < 0.05$) chlorophyll content in DW treatment (69.7) compared to TWF (60) at 12 months after planting. This was same about plant height, being 198 cm (DW) and 179 (TWF) at the same stage. All the treatment received equal volumes of water (TWF) and effluent (DW). The TWF received optimum rates of fertiliser application hence we expected vigorous growth compared to DW. Although, the effluent could not meet the nutrient requirements for banana (278 kg ha^{-1}); the crops (DW treatment) grew comparably better than TWF (Figure 2). However, some other non-experimental factors, for example inherent site fertility, affected the observed response.

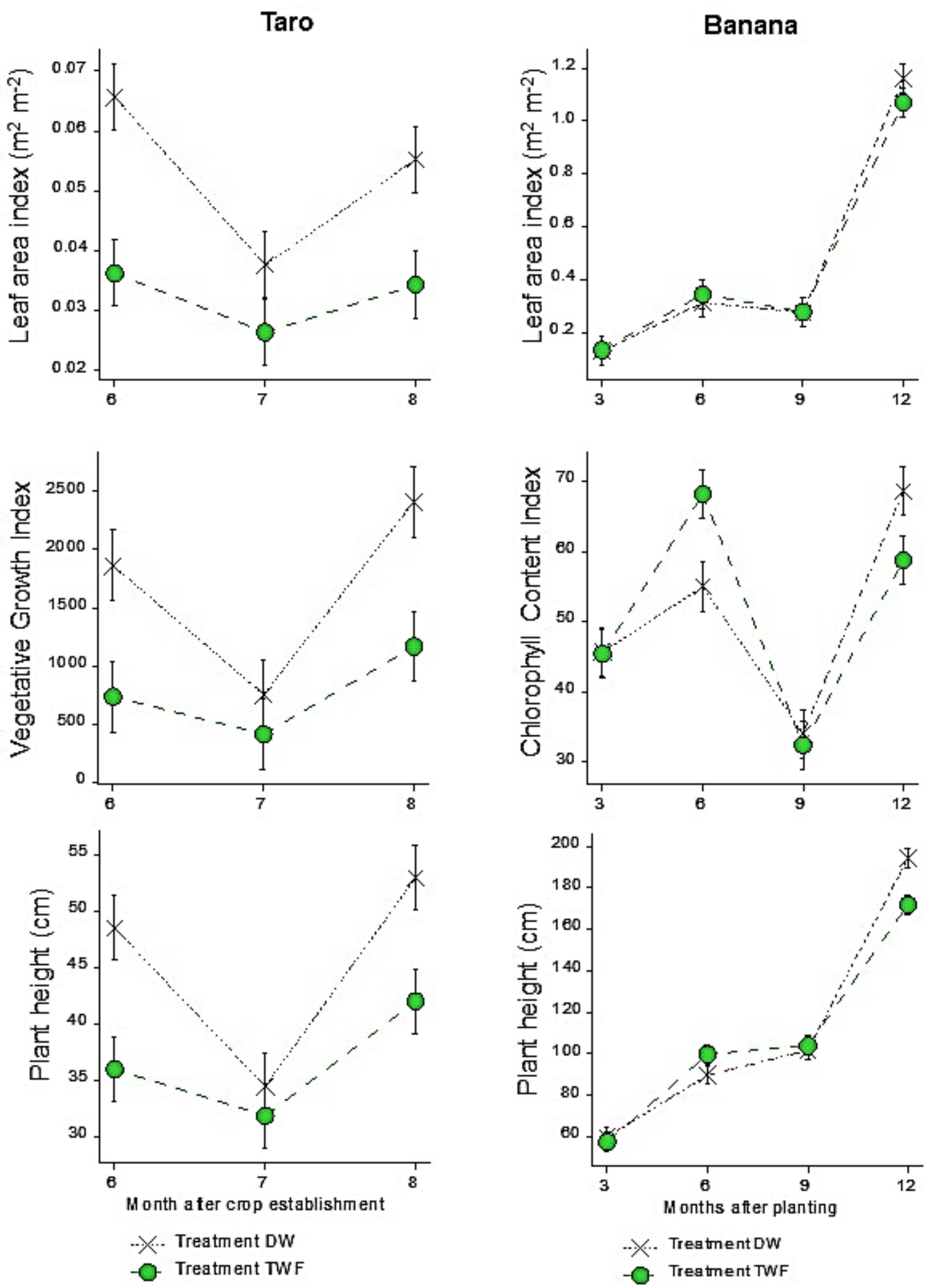

Figure 2. Growth and development for banana (plant height, chlorophyll content index and leaf area index) and taro (plant height, vegetative growth index and leaf area index).

Crop nutrient uptake

Table 4 shows total nutrient uptake per dry mass of banana and taro plants during their growing season. N and P are the elements of concern as they are responsible for environmental pollution. However in this study, no significant differences (P > 0.05) in N and P uptake were recorded in both crops. Only Mn was signficantly higher in TWF treatment (0.482 kg ha^{-1}) compared to DW (0.822 kg ha^{-1}). The reason behind could not be attributed to management practices since no Mn was applied to either treatment (DW or TWF).

Table 4. Nutrient uptake in banana and taro per crop dry mass between two irrigation treatments in an intercrop.

Treatment		**Banana**			**Taro**		
		DW	TWF	**SED**	DW	TWF	**SED**
N	**(kg ha^{-1})**	157.8^{a}	150^{a}	**19.29**	19.5^{a}	21.2^{a}	**6.19**
P		10.07^{a}	9.44^{a}	**1.6**	4.54^{a}	5.54^{a}	**1.796**
K		91.2^{a}	95.8^{a}	**19.6**	14.4^{a}	16.8^{a}	**5.23**
Ca		38^{a}	34.3^{a}	**4.43**	2.57^{a}	2.66^{a}	**0.940**
Mg		27.2^{a}	21.7^{a}	**3.83**	2.12^{a}	2.32^{a}	**0.824**
Na		0.747^{a}	0.549^{a}	**0.161**	0.47^{a}	0.65^{a}	**0.205**
Zn		0.076^{a}	0.076^{a}	**0.014**	0.19^{a}	0.19^{a}	**0.08**
Cu		0.045^{a}	0.041^{a}	**0.006**	0.012^{a}	0.014^{a}	**0.005**
Mn		0.482^{b}	0.822^{a}	**0.176**	0.034^{a}	0.033^{a}	**0.012**
Fe		0.81^{a}	0.63^{a}	**0.14**	0.730^{a}	0.660^{a}	**0.245**

*Superscripts a and b denotes means which are significantly different

Soil chemical properties

Table 5 shows soil chemical properties between the two irrigation treatments after crop harvesting. There were significant differences (P < 0.05) in MIR-N, nitrate-N, ammonium-N, P, K and pH between the two treatments and soil depths (Table 5).

MIR-N concentrations decreased with soil depths; being higher at 30 cm (DW; 3 400 mg kg^{-1} and TWF; 3167 mg kg^{-1}) than 90 cm (DW; 2 767 mg kg^{-1} and TWF; 2 867 mg kg^{-1}). Soil nitrogen content decreases with increasing soil depth [23]. At 60 cm depth in DW treatment, nitrate-N concentrations were very low (1.74 mg kg^{-1}) compared to other treatments (Table 5). Within the same treatment, (DW 60 cm) ammonium-N was significantly high compared to other treatments (36.7 mg kg^{-1}). Antagonistic relationship between ammonium and nitrates in the soil is due ammonium-nitrate transformations[16]. Results shows a significant increase in ammonium-N from 30 cm to lower depths in DW treatment (Table 5). Ammonium-N undergoes nitrification at a faster rate in layers close to the soil surface ([11]; [23]). Irrigation practices such as flood irrigation, which promote waterlogging, promote N loss through volatilisation compared to drip irrigation[15]. However, in this study drip irrigation was used hence ammonium loss was through nitrification.

There was a significant decrease in soil P from upper to lower soil layers in all treatments. At 30 cm depth, the soil P was 52.2 mg kg^{-1} (DW) and 72.5 mg kg^{-1} (TWF). Lower values were recorded at 60 cm (DW; 5.2 mg kg^{-1} and TWF; 5.3 mg kg^{-1}) and 90 cm (DW; 5.4 mg kg^{-1} and TWF; 5.3 mg kg^{-1}). Studies have shown that clay soils have Al and Fe on their exchange sites ([11];[16]), which adsorbs P hence it is less likely to move down.

There were very high K concentrations in TW treatment at 30 cm (0.645 Cmolc kg^{-1}) due to KCl fertiliser applied. Furthermore, bananas are heavy K feeders hence K fertiliser must be applied[7] so crops in DW depleted the soil K without any significant replenishment.

Table 5. Soil chemical properties collected at three soil depths between the two irrigation after crop harvest during the first season.

		DW			**TWF**			
	Unit	30	60	90	30	60	90	**SED**
MIR-N	**(mg kg^{-1})**	3400^{a}	3033^{ab}	2767^{c}	3167^{ab}	3167^{ab}	2867^{c}	**209.8**
NO_3^--N		4.87^{a}	1.74^{b}	4.12^{ab}	6.11^{a}	3.29^{ab}	3.14^{ab}	**1.522**
NH_4^+-N		20.8^{b}	36.7^{a}	31.8^{ab}	29.2^{ab}	28.4^{ab}	37.6^{a}	**6.84**
P		52.2^{a}	5.2^{b}	5.4^{b}	72.5^{a}	5.3^{b}	5.3^{b}	**14.24**
K	**($cmol_c$ kg^{-1})**	0.212^{b}	0.149^{b}	0.16^{b}	0.645^{a}	0.187^{b}	0.22^{b}	**0.078**
Ex. Acidity		0.06^{a}	0.05^{a}	0.07^{a}	0.06^{a}	0.08^{a}	0.05^{a}	**0.018**
pH	**(KCl)**	5.59^{ab}	5.87^{a}	5.5^{ab}	4.8^{b}	5.15^{ab}	5.87^{a}	**0.487**

*Superscripts a, b and c denotes means which are significantly different

Nutrient leaching

Leachates were collected in wetting front detectors at 30 and 50 cm depths between the two irrigation treatments and analysed for ammonium-N, nitrate-N and orthophosphate-P (Figure 5). No significant differences in ammonium-N, nitrate-N and orthophosphate-P between the two irrigation treatments and different depths ($P > 0.05$).

The ammonium-N concentrations in the leachates were the same in all depths (30 and 50 cm) and treatments (DW and TWF) (Figure 3). This observation agrees with studies conducted using sewage sludge; insignificant differences in ammonium-N between amended soils and controls were observed [4]. He attributed it to either low nitrification or fixation of ammonium-N to the soil particles. As described by Fonseca et al. (2007)[8], clay soils have the ability to fix ammonium-N in their sites and converts to nitrate-N through nitrification[11]. The ammonium-N could have originated from soil particles since the results are consistent with soil analysis results (Table 5).

Movement of nitrate-N is of environmental concern as it leads to the contamination of groundwater resources. The leachates analysed showed higher nitrate-N concentrations at 30 cm depth compared to 50 cm. Although the difference was not significant, upper soil layers have more concentrations of nitrates due to rapid nitrification [21]. This implies that nitrates are of less environmental concern in heavy soils since they are mostly available within top layers. With reference to Banana the root system grow down to 75 cm and the most active roots are within 60 cm depth [6]. High concentrations of nitrates down to 50 cm will be of benefit to banana growth. However, further studies on monitoring nutrient concentrations beyond 100 cm depth are important. Furthermore, the concentrations of nitrate-N in the soil can hardly be attributed to irrigation with DEWATS effluent. About 167 kg ha^{-1} of mineral N was applied to taro and banana under DEWATS effluent while the control received about 278 kg ha^{-1} but no significant differences in nitrate-N were observed between treatments (Figure 3).

Boxplots analysis explained the insignificant differences between the treatments at respective depths (Figure 5). Concerning orthophosphate-P and nitrate-N, we expected higher concentrations at 30 cm than 50 cm since clay soils at the site have a lower hydraulic conductivity. However, boxplots show that, especially in DW treatment, the concentration of orthophosphate-P was comparably higher at 30 cm depth despite outliers observed at 50 cm. Furthermore, the mean value for orthophosphate-P (50 cm depth) shows skewness to the bottom. Studies by Musazura et al. (2015)[19] revealed lower P concentrations at 50 cm depth than at 30 cm depth after irrigating Swiss chard with ABR effluent. Irrigation with dairy effluent for three years showed low movement of P from 25 cm soil depth [25]. The adsorption capacity of clay soils prevents the movement of P down the profile beyond the root zone [18]. P movements and dynamics in the soil are difficult to understand over a short period of time hence long term studies are necessary ([8]; [16]). It needs over 200 years to saturate the soil profile with P after irrigating with treated wastewater as supplementary irrigation water [14].

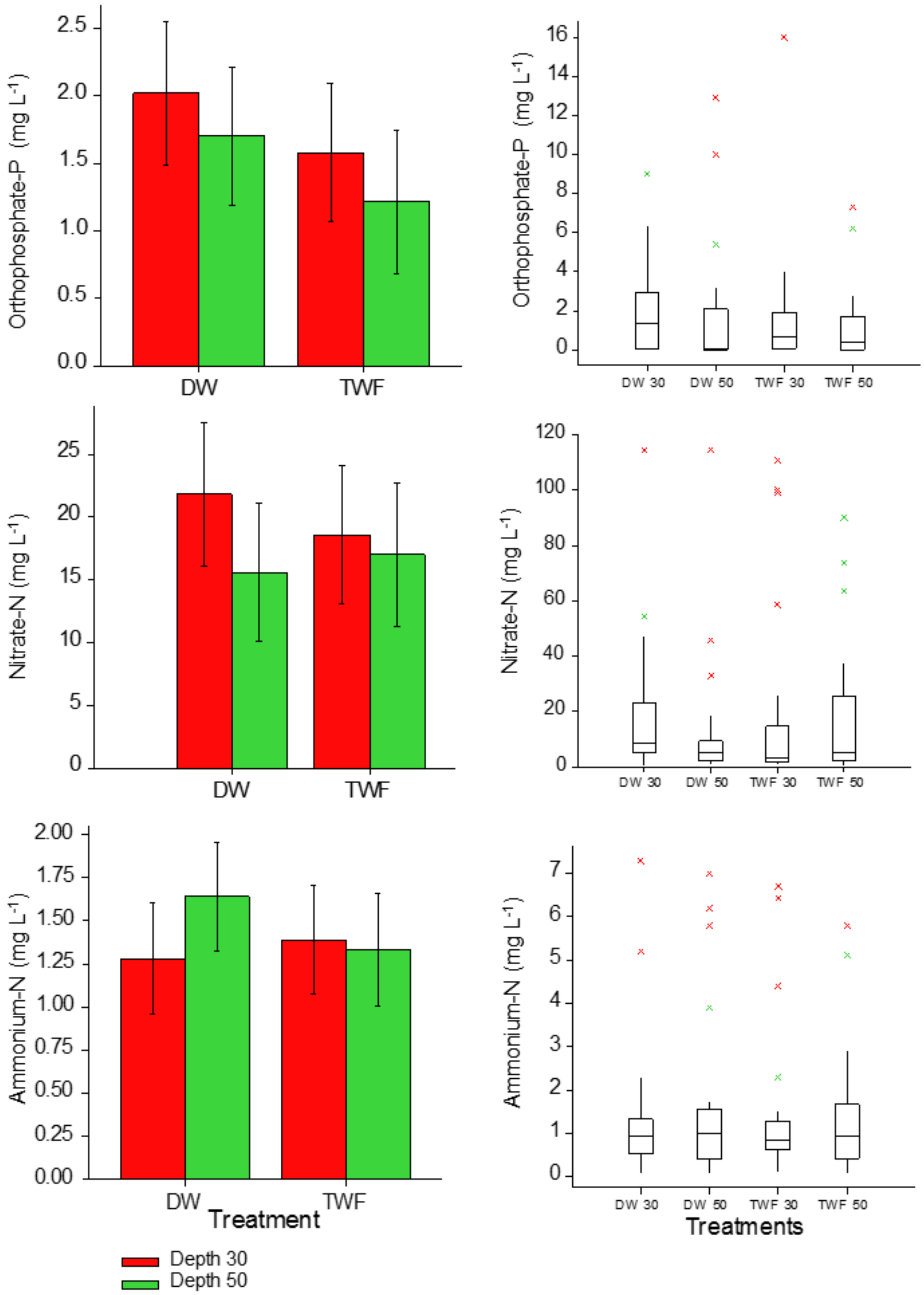

Figure 3. Leachate analysis (orthophosphate-P, nitrate-N and ammonium-N) between different treatments (DW and TWF) at 30 and 50 cm depths.

CONCLUSIONS

Crop growth rate after irrigating banana with DEWATS effluent was comparable to irrigation with tap water applied fertiliser. Banana from DEWATS effluent irrigation had a higher plant height and chlorophyll content index at 12 months after planting. Taro growth was comparably higher in DEWATS effluent compared to tap water irrigation; hence the crop did not benefit fertiliser applied to the main crop (banana).

Nutrient (N and P) uptake in taro and banana irrigated with DEWATS effluent was comparable to irrigation with tap water and fertiliser.

Soil total N decreased with depth in all irrigation treatments. Soil ammonium-N in DW treatment significantly increased with depth due to nitrification in top layers. Soil P decreased with depth; being highest at 30 cm.

Nitrate concentrations between 30 cm and 50 cm depths did not differ significantly due to the concentrations of nitrate-N already present in the soil. Orthophosphate-P was more concentrated within the 30 cm soil layer as expected.

DEWATS effluent after the HFGF treatment is an important source of irrigation water rather than nutrients; hence, its use in irrigating banana and can be undertaken without any adverse effects on the environment. Hence, this agricultural system can potentially be used to accommodate the water from the treatment system.

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