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EFFECT OF RECURRENT IRRIGATION WITH TREATED SEWAGE FROM ANAEROBIC DIGESTER COUPLED WITH ANAEROBIC BAFFLED REACTOR ON SOIL FERTILITY

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Abstract

Growing recognition of treated wastewater as a resource is among the factors influencing its reuse in agriculture worldwide. Long-term effects of irrigation with treated wastewater on soil is widely reported; however, the effect of irrigated farming cycles with treated sewage on soil fertility is rarely reported. In this study, a greenhouse maize plot experiment, consisting of triplicate plots irrigated with treated sewage and tap water, was conducted for three consecutive farming cycles. Soil was sampled for analysis at depths of 0-20 cm, 20-40 cm and 40-60 cm after every farming cycle. After the third farming cycle, pH and organic matter content increased significantly ($P \leq 0.05$) at all depths; NO_3-N and PO_4-P increased at 0-20 cm, though was not significant ($P \geq 0.05$); while EC and TDS decreased at all depths. With the exception of pH, soil organic matter content, NO_3-N, and PO_4-P, were significantly higher ($P \leq 0.05$) in plots irrigated with treated sewage for all cycles; while EC and TDS were only significant after the second farming cycle. Variation of soil parameters was not consistent with the irrigated farming cycles. Irrigation with treated sewage improved soil PO_4-P and organic matter content but posed soil alkalinity issues, thus pH amendment is needed after the third farming cycle.

Key words: Digester, farming cycle, greenhouse, recurrent irrigation, treated sewage

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1. Introduction

The use of treated wastewater for irrigation of crops is a growing practice in agricultural sector worldwide. Among the factors cited to influence water reuse in agriculture include: increasing water scarcity due to climate change, increasing population leading to increase in food and water demands, growing recognition of wastewater as a resource due to its nutrient content and growth of the agricultural sector (WHO and UNEP, 2006; Hettiarachchi and Ardakanian, 2018; Rahimi et al., 2018; Radingoana et al., 2020;). Treated wastewater as a resource provides an alternative source of water for irrigation in water-stressed areas, as well as nutrients that increase crop yield, both of which benefit farmers (Ibrahimi et al., 2022; WANG et al., 2022). However, irrigation with treated wastewater affects soil fertility depending on the source of wastewater, level of treatment and length of use which consequently affect nutrient availability, soil acidity, organic and inorganic constituents (Faruqui et al., 2009; Manjunatha et al., 2020).

Studies show that nearly 20 million hectares of land is irrigated with treated wastewater worldwide as alternative source of water for agricultural production following water scarcity (Khalid et al., 2018). This implies that if water reuse in agriculture continues blindly on the soil changes with irrigated farming cycles, the effect on soil fertility could be widespread. Despite the fact that using treated wastewater for irrigation improves soil fertility and yields, long-term application is said to have adverse impacts on soil fertility and productivity (Mohammad et al., 2007). The impact of long-term irrigation with treated wastewater depend on the nutrient levels, plant uptake efficiency, and other constituent parameters in irrigation water (Gharaibeh et al., 2016). The available literature discusses the long-term effects of irrigation with treated wastewater and the need for improved irrigation practices; however, the number of irrigated farming cycles that account for the effect is rarely mentioned. For instance, Al Omron et al. (2012) revealed that soil irrigated with treated wastewater for thirteen years had high organic matter and salinity. Bedbabis et al. (2014) indicates that irrigation with treated wastewater for four years significantly influenced changes in soil chemical properties including organic matter, soil salinity, pH, and sodium adsorption ratio (SAR). Similarly, soil irrigated with treated wastewater for 2, 5 and 10 years exhibited increased concentration of nutrients (Mohammad et al., 2007). Other findings reported increased soil organic matter content, nutrients and heavy metals in the soil irrigated with treated wastewater for three years (Mañas et al., 2009; Castro et al., 2013).

On the contrary, irrigation with treated wastewater for long term has no significant effect on the soil nutrients. According to Adrover et al. (2012), irrigation with secondary treated municipal wastewater for 20 years had no significant effect on the soil chemical properties. Thus, the available information largely focuses on the long-term impact or one-time impact of irrigation with treated wastewater on soil properties. In terms of practical application, it may be difficult to assimilate this information into irrigation management strategies for long-term irrigation with treated wastewater without significant effect on the soil properties.

The purpose of the current study was to investigate the effect of recurrent irrigation with treated sewage from the Digester coupled with Anaerobic Baffled Reactor (ABR) in series on changes of soil fertility parameters. This information sets the basis for development of irrigation management strategies for mitigation of soil effects associated with prolonged irrigation with treated wastewater.

2. Materials and methods

2.1 Description of the research site

The study was conducted at the Sanitation Biotechnologies Research Centre of Ardhi University in Dar es Salaam, Tanzania. One of the components at the Centre is a wastewater treatment plant consisting of the preliminary treatment units and the digester coupled with an anaerobic baffled Reactor (ABR) in series for treatment of domestic sewage from staff houses. The effluent from the treatment plant is stored in the underground storage tank before flowing into the nearby water body. The current study utilized the treated sewage from the treatment plant for irrigation of maize crops planted in greenhouse plots for three consecutive farming cycles. The soil texture at the experimental site is sandy-clay composed of 66% sand, 28% clay, and 6% silt.

2.2 Description of the experiment

The study was designed to investigate the impacts of recurrent irrigation with treated sewage from the anaerobic digester coupled with ABR in series on soil fertility, crop yields, heavy metals uptake and accumulation in crop produces. The experiment consisted of treatment and control plots each with three replications (Figure 1). The experimental factor included the type of irrigation water whereby treated sewage (TS) and tap water (TW) were used. The treatment entailed of plots irrigated with treated sewage while the control were the plots irrigated with tap water. The experiment was conducted in greenhouse to avoid the interference of rainfall on the soil properties and to enable association of changes in soil properties with irrigation water. Surface drip irrigation system was used to limit contacts of the farm operators with the treated sewage. Maize seeds were planted in lines spaced at 75 cm and the seed grains were spaced at 25 cm which matched with the spacing of emitters along the drip pipes (Baijuka et al., 2020). The experimental plots had lengths of 5 m and widths of 2 m.

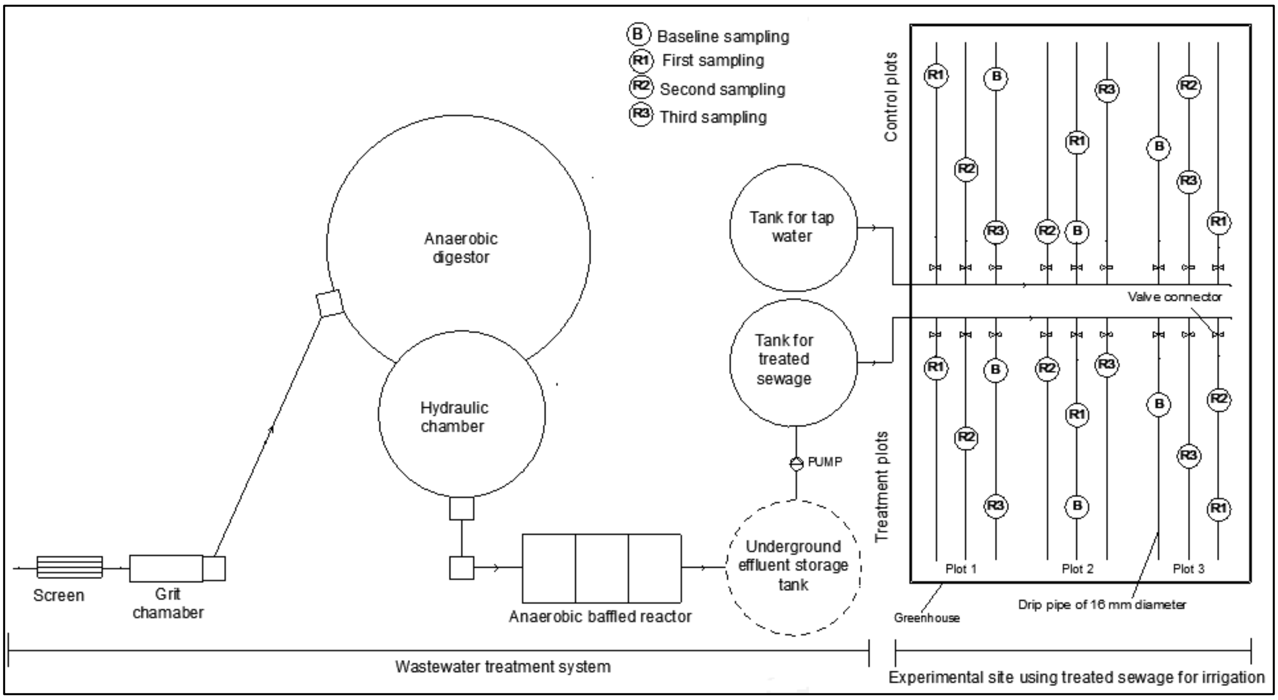

Figure 1. Layout of the experimental site showing the experimental plots and sampling points

2.3 Soil sampling

Soil samples were collected from maize experimental plots in the treatment and control plots. Initial samples were collected before planting for obtaining the baseline soil data, and then after every successive farming, for three consecutive farming cycles. Sampling after every farming cycle was meant to track changes in the soil fertility components as a result of irrigation water. Each plot had three subplots and soil samples were collected from each of the three subplots namely TP_1, TP_2 and TP_3 for treatment plots and CP_1, CP_2 and CP_3 for control plots. Sampling locations were organized to obtain samples from undisturbed soil for every sampling cycle and avoid sampling from previously sampled holes (Figure 1). According to Khaskhoussy *et al.* (2015), soil chemicals tend to accumulate in the soil at a depth of 0 - 35cm which is the root zone for most plants and the leaching chemicals can be detected beyond this depth up to 150cm. In the current study, soil samples were collected in the top soil layer (0 - 20 cm), root zone for maize plants (20-40 cm) and below the root zone for examination of the leaching nutrients (40 - 60 cm).

2.4 Processing and laboratory analysis of soil samples

The samples were air-dried under room temperature, ground using glass mortar and pestle and sieved using 2.0 mm soil sieve assembly from HACH Kit, Model SIW-1. The soil samples were analyzed for chemical parameters related to soil fertility including: Nitrate nitrogen (NO_3-N), Phosphate (PO_4^-), organic matter content (OM), alkalinity (soil pH) and soil salinity reflected by electric conductivity (EC) and total dissolved salts (TDS).

2.4.1 Analysis of soil alkalinity, electric conductivity and total dissolved salts

Soil salinity (EC), alkalinity (pH), and TDS were measured using aqueous extraction method at soil-water ratio (w: v) of 1:1 with pH/EC/TDS/Temperature tester, Hanna Combo model HI 98129 as described by Hach Co. and Hach, (1992).

2.4.2 Analysis of soil Nitrate-Nitrogen

Extraction of soil Nitrate-nitrogen was undertaken by using Calcium sulphate extraction method at 100:1 (w: w) soil-extractant ratio as detailed by Hach Co. and Hach, (1992). Analysis of Nitrate-nitrogen in the soil extract was done using Nitrate-nitrogen-Nitraver V method using the Spectrophotometer, HACH DR 4000U (Hach, 1999).

2.4.3 Analysis of soil Phosphate-Phosphorus

The available phosphorus was extracted from the soil by using Mehlich 2 extractant at 1:10 soil-solution ratio (w: v) as detailed in Hach Co. and Hach, (1992). Analysis of Phosphorus in soil extracts was performed using Phosphate-Phosver 3 method using the spectrophotometer, HACH DR 4000U (Hach, 1999).

2.4.4 Analysis of soil organic matter content

The soil organic matter content was determined by using the method described by Ridine et al. (2014). The empty crucibles and soil samples were first dried in an oven, HACH model 35 GM-2, (USA), at 105 °C for 24 hours to remove humidity. The empty crucibles were weighted (M_o) and then weighed with dry soil samples (M_1) by using digital balance, Scientech model ZSA 210 (USA). The crucibles with soil samples were placed in a muffle furnace, Vecstar model LF 3 (UK), for 3 hours at a temperature of 560 °C. After cooling, the crucible with soil residues were removed from the oven and weighted (M_2). The ash content (TC) was computed using equation (1) and was used to establish the soil organic matter content in equation (2).

$$TC = \frac{M2-MO}{M1-MO} \times 100\% \quad \text{Eq (1)}$$

Where:

M_o = Mass of the empty crucible (g); **M_1** = Mass of the crucible with dry soil sample (g) and **M_2** = Mass of the crucible with sample out of the muffle oven (g);

The organic matter content was determined using equation 1.2.

$$Mo = 100 - TC \quad \text{Eq (2)}$$

where, **M_o** = Soil organic matter content (%) and **TC** = The ash content of the soil (%).

2.5 Sampling and analysis of treated sewage

Samples of the treated sewage and tap water were collected in triplicate and analyzed once per month during the experimet (Disciglio et al., 2015). The analysis was conducted in accordance to standard methods for water and wastewater analysis, and the parameters analyzed include: Electrical conductivity (EC), pH, Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Phosphates (PO_4^-), Nitrate-nitrogen (NO_3-N), Ammonium-nitrogen (NH_4-N), Sodium (Na), Magnesium (Mg) and Potassium (K). The concentrations of Na, Ca, and Mg were used to calculate the Sodium Adsorption Ratio (SAR) (Khaskhoussy et al., 2015; Abd-Elwahed, 2018).

2.6 Statistical data analysis

Statistical data analysis was performed for each of the soil fertility parameters analyzed in the soil samples from the depths 0-20 cm, 20-40 cm and 40-60 cm. The analysis was meant to determine significant difference of the means from the treatment and control plots. Analysis of variance (ANOVA) was performed at significant level ($P \leq 0.05$) using INSTAT software.

3. Results and discussions

3.1 Irrigation water quality

The irrigation water quality results for treated sewage and tap water are presented in **Table 1**. The treated sewage was slightly alkaline with the mean pH value of 7.8±0.2. The concentration of the monitored parameters differed significantly between treated sewage and tap water. With the exception of Nitrite (NO-N) and Sodium adsorption ratio (SAR); other twelve parameters analyzed were significantly higher ($P \leq 0.05$) in treated water than in tap water. Specifically, the parameters which were significantly higher in treated sewage include: pH, EC, TDS, Nitrate (NO_3-N), ammonium nitrogen (NH_3-N), Phosphate (PO_4^-), Sodium (Na), Magnesium (Mg), Calcium (Ca), Potassium (K), BOD_5 and COD. Similar results have been reported in other studies on the difference between the treated sewage and tap water; though with varying sources of treated wastewater (Bedbabis et al., 2014; Disciglio et al., 2015). Evaluation of the treated sewage against the FAO irrigation standard reveals that parameters such as Magnesium (Mg), BOD_5, COD, NH_3-N and TDS were above the permissible levels for irrigation water; while only Magnesium (Mg) and TDS were slightly above the permissible levels in tap water. However, with the exception NH_3-N which affects susceptible cops, other parameters which were above permissible levels for irrigation water are not listed under parameters with irrigation problems.

Table 1. Properties of treated wastewater and tap water used for irrigation of maize plants in the experimental plots.

S/N	Parameters	Units	Irrigation water		FAO Standard	P-value
			Treated sewage	Tap water		
1	pH		7.8±0.2	8.25±0.1	6.0 - 9.0	≤0.05
2	EC	dS/m	0.602±0.08	0.41±0.06	2.0	≤0.05
3	TDS	mg/L	301.5±39.1	219.6±14.1	2000	≤0.05
4	Nitrate (NO_3-N)	mg/L	2.0±1.1	0.5±0.07	15	≤0.05
5	NH_3-N	mg/L	13.5±9.2	0.148±0.02	5	≤0.05
6	Nitrite (NO^-)	mg/L	0.02±0.01	0.01±0.002		ns
7	Phosphate (PO_4^-)	mg/L	37.5±4.5	1.94±0.8		≤0.05
8	Sodium (Na)	mg/L	42.2±1.3	19.8±1.0		≤0.05
9	Magnesium (Mg)	mg/L	32.3±3.1	6.4±0.4	0.2	≤0.05
10	Calcium (Ca)	mg/L	58.4±2.9	17.8±4.2		≤0.05
11	Potassium (K)	mg/L	29.1±1.6	9.8±3.6		≤0.05
12	BOD_5	mg/L	77.0±36.0	11.4±1.2	30	≤0.05
13	COD	mg/L	109.0±29.7	32.5±3.3	90	≤0.05
14	SAR	Meq/L	1.096±0.02	1.022±0.06	6	ns

***BOD5**: Biochemical oxygen demand at 5 days; **COD**: Chemical oxygen demand**; SAR**: Sodium adsorption ratio; **TDS**: Total dissolved salts; **EC**: Electrical conductivity, **ns**: not significant. Data are Mean ± standard deviation (n=5).*

3.2 Effect of recurrent irrigation with treated sewage on soil fertility parameters

3.2.1 Effect of irrigation with treated sewage on soil TDS

The results on the effect of irrigation with treated sewage on the TDS for three consecutive farming cycles are shown in **Figure 2**. Irrigation with treated sewage increased soil TDS after the first and second farming cycles, and decreased after the third farming cycle. However, a significant increase ($P \leq 0.05$) was observed after the second farming cycle at the depth of 20-40 cm; and the increase was from 223.5±27.3 mg/L to 293.3±29.3 mg/L ($P = 0.0458$). The increase of soil TDS after irrigated farming is associated with concentration of dissolved salts in the irrigation water as previously reported (Disciglio et al., 2015). Recurrent irrigation with treated sewage for the third farming cycle decreased the soil TDS, and a significant decrease was particularly at the depths 20-40 cm ($P = 0.0496$) and 40-60 cm ($P = 0.0228$). The decrease of soil TDS with recurrent irrigated farming cycle may be associated with leaching of cations below the sampling depths in line with Bedbabis et al. (2014) and Disciglio et al. (2015) who had similar findings. Irrigation with tap water also increased TDS after the first farming cycles at all depths; but significant increase was only observed at the depth of 20-40 cm (P = 0.04570) similar to that of treated sewage. Repeated irrigation with tap water also decreased TDS, and a significant decrease was observed at the depth of 20-40 cm after the second farming cycle (P = 0.0102) and third farming cycle (P = 0.0209). The increase of TDS was attributed to the accumulation of salts from irrigation water while the decrease was due to leaching of salts upon recurrent irrigation. It was further found that the changes of soil TDS were inconsistent with farming cycles for treated sewage and tap water.

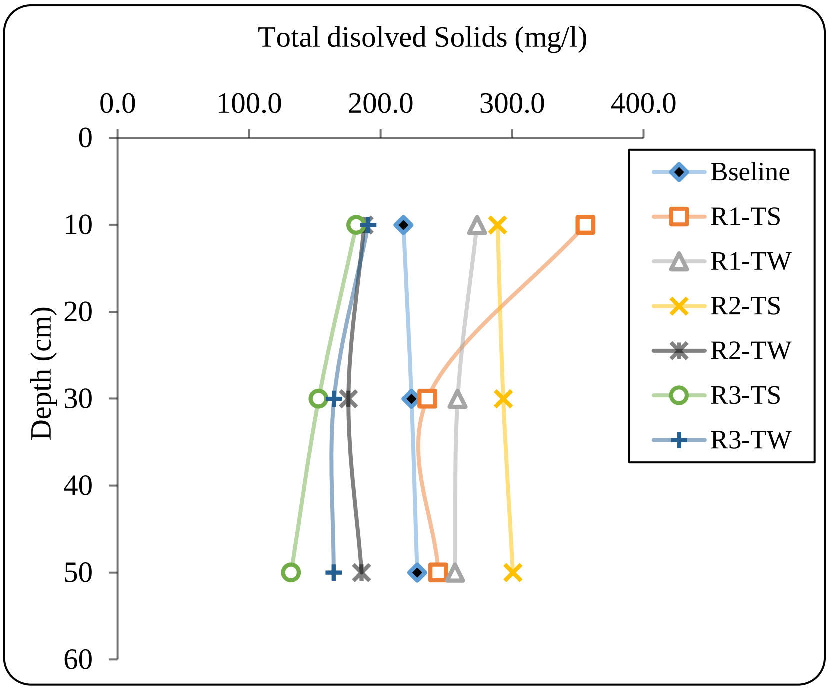

Figure 2. Effect of irrigation water on the soil TDS at different depths and faming cycles.

Comparison of TDS for plots irrigated with treated sewage and tap water showed a significant difference ($P \leq 0.05$) only after the second farming cycle. The difference was observed at all sampled depths: 0-20 cm (P = 0.0140), 20 - 40 cm (P = 0.0027) and 40 - 60 cm (P = 0.0095). This could be partly associated to the observed difference of TDS in treated sewage (301.5±39.1 mg/L) and tap water (219.6±14.1 mg/L). However, previous studies have reported significant effect of treated sewage on soil TDS in the upper soil layers only (Mansouri et al., 2014), while other studies reported the changes in lower soil layers (Khaskhoussy et al., 2015). Therefore, the values of TDS are not always higher at all depths in soil irrigated with treated sewage. In addition to the effect of irrigation water, soil TDS could be influenced by soil factors including the soil pH and organic matter (Adejumobi et al., 2014; Mansouri et al., 2014; Khaskhoussy et al., 2015).

3.2.2 Effect of irrigation with treated sewage on soil salinity

The changes of soil salinity (EC) with recurrent irrigation using treated sewage are presented in **Figure 3.** Irrigation with treated sewage increased the EC after the first and second farming cycles at all depths.

However, a significant increase was observed after the second farming cycle at the depth of 0-20 cm, whereby the increase was from 0.4±0.06 dS/m to 0.6±0.005 dS/m (P = 0.0446). The increase of salinity may be associated with high concentration of salts in treated sewage denoted by TDS (Bedbabis et al., 2014; Disciglio et al., 2015; Hettiarachchi and Ardakanian, 2018). Further irrigation with treated sewage for the third farming cycle reduced EC at all depths, but a significant decrease was observed at the depth of 40 - 60 cm (P = 0.0386), where it decreased from 0.4±0.06 dS/m to 0.3±0.006 dS/m. The decreases of the EC after the third farming cycle, may be attributed to leaching of cations from the soil beyond the sampling depths (Bedbabis et al., 2014a, 2015). Irrigation with tap water increased EC after the first farming cycle only and a significant increase was observed at the depth of 0-20 cm (P = 0.0229). Repeated irrigation with tap water also decreased the EC significantly at the depth of 20 - 40 cm for the subsequent second (P = 0.0073) and third (P = 0.0282) farming cycles. The results show that the changes of soil EC were inconsistent with recurrent irrigated farming cycles as it increased and dropped sharply in the third farming cycle. This may be associated with factors such as leaching of cations due to regular irrigation (Bedbabis et al., 2014); and alterations of equilibriums of some soil processes such as adsorption and cation exchange between soil colloids and the soil solution.

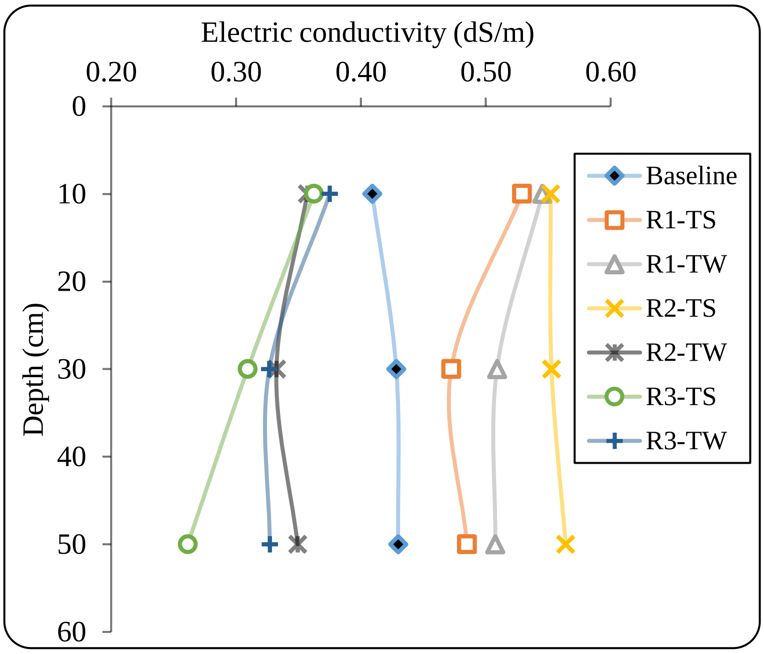

Figure 3. Effect of irrigation water on the soil EC at different depths and faming cycles.

Comparing the levels of EC for plots irrigated with treated sewage and tap water, the results revealed that EC was significantly higher for plots irrigated with treated sewage after the second farming cycle. The high EC values were observed at all depths; 0-20 cm (P = 0.0135); 20-40 cm (P = 0.0028) and 40-60 cm (P = 0.0098). The observed difference may be attributed to the concentration of salt and TDS in treated sewage relative to tap water (Bedbabis et al., 2015).

3.2.3 Effect of irrigation with treated sewage on soil pH

The findings revealed a mixed effect of irrigation with treated sewage on soil pH: after the first farming cycle though, there was no significant change in soil pH with respect to the baseline soil pH; after the second farming cycle pH decreased significantly ($P \leq 0.05$), and it increased significantly ($P \leq 0.05$) after the third farming cycle (**Figure 4**).

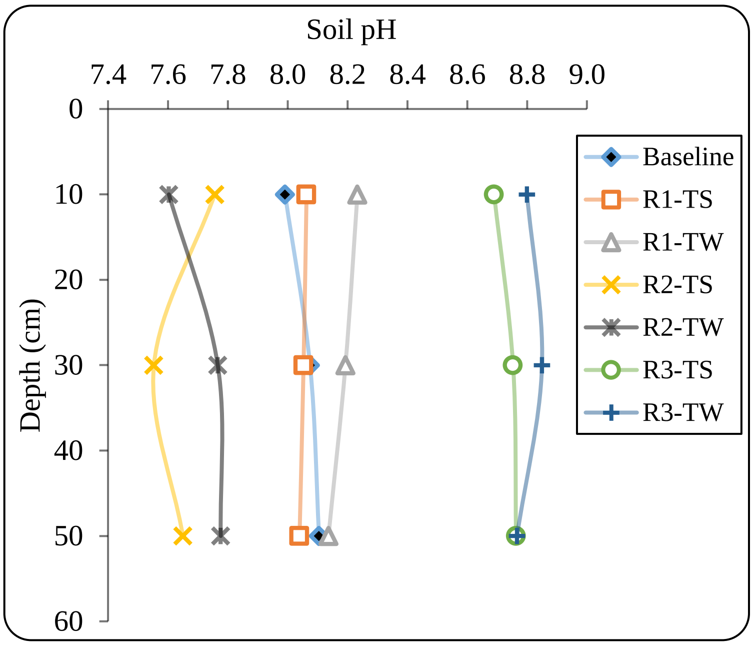

Figure 4. Effect of irrigation water on the soil pH at different depths and faming cycles.

The observed pH decrease after the second farming cycle was from 8.0±0.14 to 7.8±0.008 (P = 0.0081) at 0-20 cm; 8.1±0.05 to 7.6±0.11 (P = 0.002) at 20-40 cm and 8.1±0.06 to 7.7±0.06 (P = 0.0003) at 40-60 cm. Similar findings were observed for plots irrigated using tap water, except that a significant pH decrease was only observed at the depth of 40-60 cm (P = 0.0018). According to the USDA classification, such change is low since it shifted the soil class from moderately to slightly alkaline. The decrease of soil pH is associated with decomposition of organic matter in treated sewage producing humic and fulvic acid, leaching of basic cations, and nitrification of ammonium or uptake of ammonia ions by plants (Bedbabis et al., 2014). This finding is consistent with earlier studies (Adejumobi et al., 2014; Bedbabis et al., 2014; Khaskhoussy et al., 2015). Furthermore, the soil pH increased after the third farming cycle from 8.0±0.14 to 8.7±0.08 (P = 0.0004) at 0-20 cm, 8.1±0.05 to 8.8±0.06 (P = 0.0002) at 20-40 cm and from 8.1±0.03 to 8.8±0.02 (P = 0.0001) at 40-60 cm. The soil pH increased beyond 8.4 value, indicates a salt affected soil due to accumulation of basic cations and exchangeable sodium in soil associated with recurrent or long term effect of irrigation with effluents (To and Christen, 1993; Disciglio et al., 2015). The finding is in line with previous studies on long term effect of irrigation with treated sewage (Disciglio et al., 2015; Albalawneh et al., 2016). Similar results were obtained for plots irrigated with tap water after the third farming cycle. The comparison of plots irrigated with treated sewage and those irrigated with tap water revealed no significant difference at all sampled depths for all three consecutive farming cycles.

3.2.4 Effect of irrigation with treated sewage on organic matter content

Results on the changes of soil organic matter (OM) at different depths and farming cycles are shown in **Figure 5**. With respect to the baseline soil OM, irrigation with treated sewage significantly increased ($P \leq 0.05$) the soil organic matter content. After the first and third farming cycles, the soil OM increased at all sampled depths; while after the second farming cycle the increase was only observed at 0-20 cm. After the first farming cycle, the soil organic matter increased from 2.5±0.4 % to 5.5±0.5 % ($P = 0.0006$) at 0-20 cm; 2.6±0.2% to 7.1±1.3% ($P = 0.0037$) at 20-40 cm and 2.3±0.4% to 6.5±0.3 % ($P = 0.0001$) at 40-60 cm. The increase of soil organic matter content is beneficial in improving soil fertility, since it improves soil aggregate stability, water retention and produce ammonium nitrogen on decomposition which is a nutrient to plants (Adejumobi et al., 2014). The increase of soil organic matter content after one-time irrigation with treated sewage was reported by other authors (Adejumobi et al., 2014; Disciglio et al., 2015); and is attributed to BOD and COD contents in the treated sewage (Adejumobi et al., 2014). In addition to the levels of BOD and COD in treated sewage, the observed changes in soil organic matter could also be attributed to sampling variability and organic residues of roots of maize plants. After the second farming cycle, a significant increase of soil OM was observed only at the depth of 0-20 cm, where it increased from 2.5±0.4 % to 3.6±0.3 % ($P = 0.03790$) and decreased significantly with depth ($P = 0.008$) at 40-60 cm. However, the OM decrease after the second farming cycle is attributed to bio-decomposition of the soil OM (Khaskhoussy et al., 2015; Albalawneh et al., 2016). After the third farming cycle, the soil OM increased significantly from 2.5±0.4 % to 4.1±0.1 % ($P = 0.0042$) at 0-20 cm deep; 2.6±0.2 % to 4.2±0.5% ($P = 0.0034$) at 20-40 cm and from 2.3±0.4 % to 3.9±0.4% ($P = 0.003$) at 40-60 cm. The increase of soil OM was attributed to the recurrent irrigation with treated sewage with high concentrations of BOD and COD in agreement with previous studies (Mapanda et al., 2005; Bernier et al., 2013).

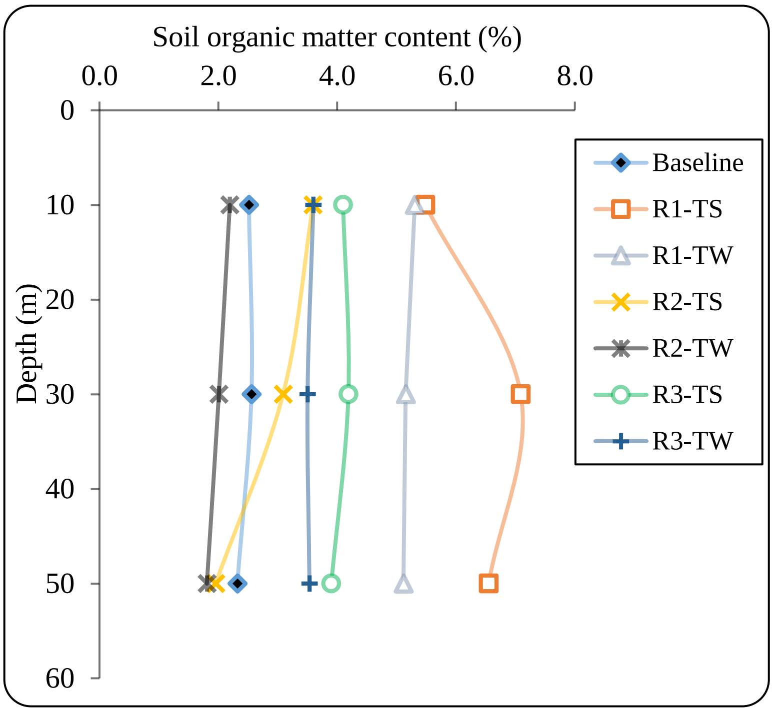

Figure 5. Effect of irrigation water on the soil organic matter content at different depths and faming cycles.

It was noted that the increase of OM content from one farming cycle to the other was not consistent which may be attributed to the variations in microbial activities decomposing the soil OM and fluctuations of quality of the treated sewage particularly the BOD_5 and COD (Disciglio et al., 2015). Comparing the results for plots irrigated with treated sewage and tap water, it was revealed that plots irrigated with treated sewage had significantly higher OM after the second farming cycle ($P = 0.0149$) and third farming cycle ($P = 0.0123$) at the depth of 0-20 cm. After the first farming cycle, treatment plots had significantly higher OM at the depth of 40-60 cm ($P = 0.0081$).

3.2.5 Effect of irrigation with treated sewage on soil Nitrate-nitrogen

Results of the effect of irrigation of maize using treated sewage on the soil NO_3-N for three consective farming cycles are presented in **Figure 6**. It was observed that irrigation using treated sewage reduced soil NO_3-N after the first and third farming cycles. Notable decrease of soil NO_3-N after the first irrigation cycle was observed at soil depths of 20-40 cm and 40-60 cm but this was not statistically significant. A significant decrease was observed after the third farming cycle at the depth of 40-60 cm from 10.5±2.0 mg/l to 6.0±0.6 mg/l ($P = 0.0348$). The decrease of NO_3-N aftter irrigated farming cycle may be attributed to high uptake by maize plants meaning that NO_3-N added by treated sewage and that of soil was only suffficient for growth of maize plants. Other possible factors for decrease of the NO_3-N after irrigation with treated sewage include volatilization favoured by soil alkalinity and leaching (Disciglio et al., 2015; Erel et al., 2019). Despite of the decrease after the first and third farming cycles, NO_3-N increase was observed after the second farming cycle at the depths 20-40 cm and 40-60 cm and after third farming cycle at 0-20 cm though the increase was insignificant. Increase of NO_3-N at the lower depths, may be due to leaching from the upper layer (0-20 cm) on recurrent irrigation (Disciglio et al., 2015). Increased NO_3-N in the upper layer after the third farming cycle may be associated with nitrogen components in the treated sewage on recurrent irrigation and the decompsition of the organic matter which produces NH_4-N that is readily converted into NO_3-N (Disciglio et al., 2015; Salgado-Méndez et al., 2019; Tsigoida and Argyrokastritis, 2019).

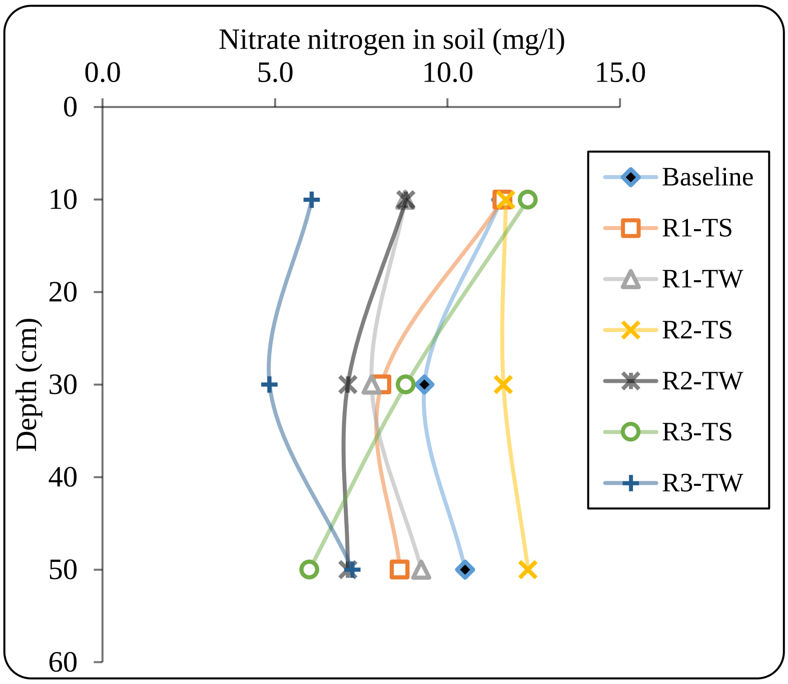

Figure 6. Effect of irrigation water on soil NO_3-N at different depths and faming cycles.

Irrigation with tap water reduced soil NO_3-N at the sampled depths for all farming cycles. A significant decrease of NO_3-N was observed after the third farming cycle at the depth of 0-20 ($P = 0.0086$) and 20-40 cm ($P = 0.0132$). Comparison of results for plots irrigated with treated sewage and tap water revealed that soil NO_3-N was significantly higher ($P \leq 0.05$) in plots irrigated with treated sewage after the second and third farming cycles. The differences were observed at the depths of 20-40 cm ($P = 0.0138$) and 40-60 cm ($P = 0.0327$) after the second farming cycle; and at 0-20 cm ($P = 0.0008$) and 20-40 cm ($P = 0.0077$) after the third farming cycle. This was attributed to the difference in the nitrogen and organic matter concentrations of the treated sewage and tap water, in line with previous studies (Tsigoida and Argyrokastritis, 2019).

3.2.6 Effect of irrigation with treated sewage on soil Phosphate-phosphorus

The effect of irrigation with treated sewage on the soil phosphate phosphorus for three consective farming cycles is presented in **Figure 7.** With respect to the baseline soil Phospate, irrigation of maize plots with treated sewage increased the concentration of soil phosphate phosphorus after the first and second farming cycles.

However, the increase was only significant after the first farming cycle at the depth of 0-20 cm where it increased from 22.7±1.0 mg/l to 55.8±6.5 mg/l (P = 0.0194). After the third farming cycle, the soil phospgate increased at the depth of 0-20 cm and decreased at the depth of 40-60 cm but the changes were not significant. The increase of soil phosphate especially in top soil layer (0-20 cm) improves soil fertility and could be associated with high soluble phosphate (37.5±4.5 mg/l) and organic matter content in treated sewage as reported by other studies (Bedbabis et al., 2014; Erel et al., 2019).

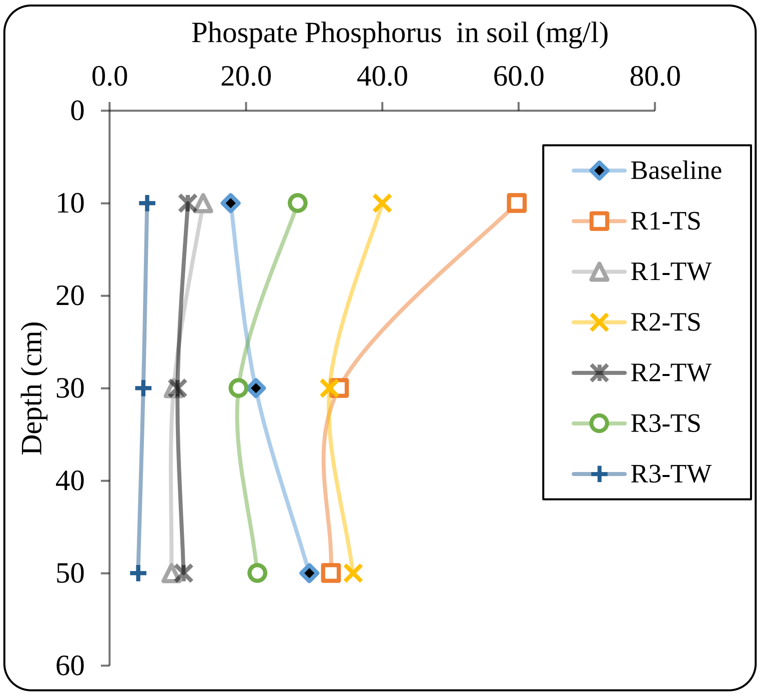

Figure 7. Effect of irrigation water on soil phosphate at different depths and faming cycles.

Results showed consistent decrease of the soil Phosphate with recurrent irrigated farming cycles despite the fact that treated sewage contained high Phosphate concentration as compared to tap water. This was probably caused by leaching and progressive uptake by maize plants. Soil phosphate was significantly higher ($P \leq 0.05$) in all plots irrigated with treated sewage compared to those irrigated with tap water for the three consecutive farming cycles. The difference was observed at all depths as follows: after the first farming cycle 0-20 cm (P = 0.004), 20-40 cm (P = 0.0348) and 40-60 cm (P = 0.005); after the second farming cycle 0-20 cm (P = 0.0053), 20-40 cm (P = 0.0057) and 40-60 cm (P = 0.0293) and after the third farming cycle 0-20 cm (P = 0.0381), 20-40 (P = 0.0027) and 40-60 cm (P = 0.047). The findings are in good agreement with the previous studies (Bedbabis et al., 2014; Erel et al., 2019). On the contrary, the findings contrasts with what was reported by Disciglio et al. (2015), where high level of Phosphate in treated sewage had no significant effect on soil

Phosphate. The amount of soluble Phosphate and organic matter in treated sewage and clay content in the soil determine the amount of available phosphate in the soil irrigated with treated sewage (Bedbabis et al., 2014).

3.3 Implication of the findings

Recurrent irrigation of maize in the greenhouse with treated sewage from the anaerobic digester coupled with ABR for three consecutive farming cycles was observed to have both positive and negative impacts on the soil. On the positive side, recurrent irrigation of greenhouse maize improved soil OM, PO_4-P and slightly increased NO_3-N in the upper soil layer at the end of the third farming cycle, which is beneficial to soil fertility. On the negative side, recurrent irrigation of the greenhouse maize with treated sewage for three consecutive farming cycles increased soil pH from 8.06 to 8.7 at the end third farming cycle with an increment of 0.64 (7.9%). The pH value after the third farming cycle was above the permissible value of 8.4 for agricultural land. However, the increase of pH from one farming cycle to the other was not consistent as it decreased after the second farming cycle. Therefore, when irrigating maize in the greenhouse with treated sewage from the anerobic digester with ABR, it is advised to check the soil pH after each farming cycle and before starting the subsequent recurrent farming cycle. According to the findings of the current study, soil amendments for reduction of soil pH need to be implemented after the third farming cycle. Methods reported for soil amendments for reduction of pH include: application of organic matter, crop rotation with alkalinity tolerant crops such a rice and wheat, application fly ash, alternation of clean water and treated sewage for irrigation and application of chemical methods including elemental Sulphur, aluminium sulphated and Iron sulphate (Minhas and Sharma, 2003; Mickelbart and Stanton, 2008).

4. Conclusions

Based on the results of this study, recurrent irrigation with treated sewage from the anaerobic digester coupled with ABR in series significantly improved soil fertility parameters ($P \leq 0.05$) namely soil organic matter content, NO_3-N and PO_4-P after the third farming cycles which is beneficial to crop yields. Variations of the soil fertility parameters monitored including TDS, EC, pH, organic matter content, NO_3-N and PO_4-P were inconsistent with the number of irrigated farming cycles; which imply the necessity for soil analysis after each farming cycle to inform the needs and required soil amendment. With the observed improvement in soil fertility parameters, recurrent irrigation with treated sewage from the digester coupled with ABR in series resulted in significant ($P \leq 0.05$) increase on soil pH beyond the acceptable limit of 8.4 after the third farming cycle. Thus, irrigation management strategies are needed for pH amendment after the third farming cycle when using treated sewage from the digester coupled with ABR to sustain maize yield in the greenhouse. Also, similar studies need to be conducted with other types of crops as they have different nutrient uptake efficiencies.

Authors contribution statement

The authors confirm contribution to the paper as follows: study conception and design: Jonas Gervas Balengayabo, Gabriel R. Kassenga and Shaaban M. Mgana; data collection: Jonas Gervas Balengayabo; analysis and interpretation of results: Jonas Gervas Balengayabo; draft manuscript preparation: Jonas Gervas Balengayabo and Fredrick Salukele. All authors reviewed the results and approved the final version of the manuscript.

Conflict of interest statement

No competing interest declared.

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