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Effect of Treated Wastewater from Anaerobic Digester Coupled with Anaerobic Baffled Reactor as Fertigation on Soil Nutrient Residues, Growth and Yield of Maize Plants

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ABSTRACT: Water scarcity, wastewater management and growing food demand associated with global population increase, are among the drivers cited for water reuse in agriculture. The current study intends to contribute on the influence of treated wastewater from the anaerobic digester coupled with anaerobic baffled reactor (ABR) as a fertigation on soil nutrient residues, growth and yield attributes of maize plants by using surface drip irrigation system to apply the treated wastewater. The experiment consisted of experimental plots irrigated with treated wastewater and control plots irrigated with tap water; all with three replications. The treated wastewater was lightly alkaline with pH of 7.8±0.2 and high concentration of nutrients than tap water, but were within the acceptable levels. Fertigation with treated wastewater improved soil fertility evidenced by significant improvement ($P \leq 0.05$) in plant height, leaf area Index (LAI) and maize yield. Plant height was 1.5 times taller and LAI was about 2.5 times more in treatment than in control plots. Yield attributes in experimental plots including number of grains per cob, (97±11.3); weight of grains per cob, (80.7±7.9 g); mass of 100 grains, (35.0±3.5 g), and grain yield, (745.8±62.9 Kg/ha) were significantly higher ($P \leq 0.05$) compared to their counterpart control plots. The grain yield in experimental plots was about 37% higher than the yield in control plots. Therefore, fertigation with treated wastewater from the anaerobic digester coupled with ABR improves maize yield and is advisable in areas with water scarcity.

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Water scarcity, management of wastewater and growing food demand associated with global population increase, are among the drivers cited for water reuse in agriculture (Jovanovic, 2008; Jimenez and Asano, 2015; Massoud *et al.*, 2018). Prolonged dry periods affect agriculture resulting in food shortage and economic losses (Jimenez and Asano, 2015). About 70% of water extracted from all sources in the world is used for irrigation (Siebert *et al.*, 2010), implying that agriculture as the life supporting sector is severely affected by water scarcity. With water scarcity, it should be noted that 70%-80% of water supplied for domestic uses becomes wastewater, which is managed through collection, conveyance, treatment, and disposal into the environment; mostly in water bodies (Massoud *et al.*, 2018). Reuse of treated wastewater for fertigation of crops provides numerous benefits, including management of treated wastewater, reliable food production, and nutrient recovery from treated wastewater (Al Arni *et al.*, 2022; Angelakis *et al.*, 2018). Treated wastewater contains nutrients and organic matter at varying quantities that may improve soil fertility for growth and yield of various crops when used for fertigation (de Lemos *et al.*, 2021; Dhakshanamoorthy Dinesh *et al.*, 2021; Elamin *et al.*, 2020). In Tanzania, maize is a

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staple food for 80% of the population (Mkonda and He, 2017), and 90% of households in Tanzania Mainland grow maize (NBS, 2014), therefore using treated wastewater for fertigation of maize could contribute to reliable food production for the majority; however, this has not yet received adequate attention. More than 10% of the world population consume food irrigated with wastewater (Ungureanu *et al.,* 2020), but the adoption rate is very low in developing countries probably due to little locally available evidence on its benefits on crop yield. With a growing population posing high demand for food and management of treated wastewater calls for integrated approach that benefits the population and the environment. The current study intends to contribute knowledge on the influence of treated wastewater from the anaerobic digester coupled with anaerobic baffled reactor (ABR) on soil nutrient residues, growth and yield attributes of maize (Zea mays L.). Studies on the use of treated wastewater for irrigation of maize are available for different sources of wastewater treated using various technologies with variable results on maize yield. In India maize was fertigated with distillery and beverage effluents; in Iran, South Africa and Sudan maize was irrigated using effluents of municipal wastewater treatment plants; and in all cases the growth and yield attributes of maize were improved (Bame *et al.,* 2014; Mousavi and Shahsavari, 2014; Elamin *et al.,* 2020; D. Dinesh *et al.,* 2021; Ku *et al.,* 2021). Additionally, irrigation with diluted raw wastewater was also reported to improve growth and yield components of maize similar to treated wastewater (Alabadi *et al.,* 2018; Younas *et al.,* 2020). On the contrary, effluent from treatment plant of domestic wastewater may not provide sufficient nutrients needed for plant growth. This was reported by Da Fonseca *et al.* (2005), in which irrigation with treated wastewater could not improve maize yield when compared with well water. This may partly be attributed to the source of wastewater or the treatment technology employed which affect the quantity of nutrients and other soil amendment components in the treated wastewater. The contribution of this study to the previous studies relies on the fact that the wastewater is generated from staff houses, consisting of a small community of relatively similar lifestyle which may affect the constituents of the wastewater. Additionally, the wastewater generated is treated by using a compact model of wastewater treatment system consisting of anaerobic digester (AD) in series with anaerobic baffled reactor (ABR) as the main secondary treatment units. This wastewater treatment system receives purely domestic wastewater inflow with low likelihood of heavy metals, which makes the treated wastewater from this system the promising source of irrigation water. Furthermore, combination of the two anaerobic rectors in series improves the performance on the removal of organic matter, but the effluent still contains appreciable amount of nitrogenous, phosphorus and metallic nutrients which constitute the economic value as fertilizer. Thus, the treated wastewater from the anaerobic digester coupled with ABR may offer irrigation water and nutrients for plants and its application for irrigation is best described as fertigation. In view of the foregoing, the current study aimed to assess the effect of fertigation with treated wastewater from the anaerobic digester coupled with ABR in series on the soil nutrient residues after harvesting and the effect of the same on the growth and yield attributes of maize plants grown under field conditions.

MATERIALS AND METHODS

Description of the research site: The study was conducted at Ardhi University Sanitation Biotechnologies Research Centre. One of the components of the Centre, is a wastewater treatment plant for treatment of domestic wastewater from the staff houses. The treatment plant consists of preliminary treatment units and an anaerobic digester coupled with an anaerobic baffled Reactor (ABR) in series as secondary treatment units. The effluent from the treatment plant is stored in the underground storage tank before being discharged to the nearby water body. The study utilized this effluent for irrigation of maize experimental plots. The soil texture at the experimental site is sandy-clay, with 66% of sand, 28% of clay and 6% of silt.

Description of the experiment: The study was designed to investigate the effect of treated wastewater on the growth and yield attributes of maize plants. Experimental and control field plots were established in three replications and results the on growth and yield attributes were analyzed for comparison. The experimental plots (EP) consisted of plots irrigated with treated wastewater while the control experimental plots (CP) consisted of plots irrigated with tap water. The treated wastewater from the Sanitation Biotechnologies Research Centre was pumped from the underground storage tank to the elevated tank from which it was supplied to the experimental plots through the drip irrigation system. Surface drip irrigation system was installed to limit contacts of the farm operators with the treated wastewater. The drip irrigation system consisted of 16 mm drip pipes; and fittings including start connectors, valve connectors, end connectors and emitters. Maize seeds were planted in lines spaced at 60 cm and maize seeds were spaced at 25 cm which was also the spacing of emitters along the drip pipes. Maize seeds were obtained from the licensed seed suppliers at Mwenge Dar es Salaam and had 85% germination.

Sampling and monitoring of growth attributes of Maize plants: Sampling of maize plants was done according to the method by Buriro *et al.,* (2015), whereby 22 and 20 maize plants were respectively sampled from experimental and control plots. Systematic random sampling was used to get the sampled number of plants. Non-destructive method was used for monitoring plant growth attributes. The growth attributes monitored for maize plants were plant height, number of leaves, length of leaves and width of leaves (D. Dinesh *et al.*, 2021; Ku *et al.*, 2021; Onuorah, 2021). The number of leaves, length and width of leaves were used for determination of the Leaf Area Index (LAI) for maize plants as per method by Dinesh *et al.,* (2021) as shown in equation (1).

$$\mathrm{LAI} = \frac{\mathrm{L \times N \times B \times 0.796}}{\mathrm{Spacing\ (cm)}} \ldots\ldots\ldots\ldots\ldots (1)$$

L: length of the leaf (cm), B: breath of the leaf (cm), N: number of leaves and 0.796 is a constant.

Growth attributes of maize plants: Plant Heights of maize plants were taken for sampled plants in the experimental and control plots. Measurements of plat heights were taken by using a measuring tape from the soil level to the apex of the highest panicle of the plants. The first measurement was taken 21 days after planting (DAP), thereafter at an interval of one week. The leaf length was measured from the pointy part at one end of the leaf to the point where the leaf joins the stalk of the plant at the other end. The leaf width was measured at the broadest part of the leaf; while the number of leaves was physically counted (Wood and Roper, 2014).

Yield attributes of Maize: The maize cobs were removed from the maize stalk and sun dried then the husks and silks were removed. In determination of yield attributes maize cobs were randomly sampled from each plot. The yield attributes used were cob length, number of kernel rows per cob, number and mass of grains per cob, mass of 100 grains and grain yield (D. Dinesh *et al.,* 2021; Ku *et al.,* 2021; Onuorah, 2021) as clearly explained bellow.

Cob length and number of kernel rows per cob: The cob lengths were measured using measuring tape and recorded in centimeters (cm). Kernel rows was counted for each sampled cob and the number of kernel rows was recorded for all cobs. The average cob length and number of kernel rows per cob was determined and analyzed for cobs from experimental and control plots.

Number and weight of grains per cob: After counting the number of kernel rows, the grains were shelled. The number of grains and mass of grains were determined for each cob. The average number of grains per cob and their respective mass per cob were determined and compared for experimental and control plots.

Mass of 100 seeds: 100 number of grains were picked randomly from all of the harvested maize per plot and weighted. Three replicates were established for each plot and their averages were compared between experimental and control plots.

Grain yield: Grain yield is mass of dry maize grains harvested per unit area, it is expressed in Kilogram (Kg) per hectare (ha) or (Kg/ha) (D. Dinesh *et al.,* 2021; Ku *et al.,* 2021; Onuorah, 2021). After harvesting, the maize cobs were sun dried and then shelled to get maize grains per plot for determination of the grain yield.

Sample collection and analysis of irrigation wastewater: Samples of the treated wastewater and tap water were collected periodically during the experiment and analyzed in accordance with standard methods for water and wastewater analysis. The parameters analyzed include: pH, Electrical conductivity (EC), Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Nitrate-nitrogen (NO_3-N), Ammonium-nitrogen (NH_4-N), Phosphates (PO_4^-), Potassium (K), Sodium (Na), Magnesium (Mg) and heavy metals, including Cadmium (Cd), Nickel (Ni) and Zinc (Zn) as shown in Table 1. Sodium adsorption ratio (SAR) was determined using standard formula.

Soil sampling and analysis of nutrient residues: The samples of soil were collected from the experimental plots before and after irrigation for analysis of soil nutrient residues as indicators of soil fertility. The soils samples were taken at the depth of 0-40 cm which falls within the root zone of most plants including maize (Khaskhoussy *et al.,* 2015). The samples were dried under room temperature, ground using a glass mortar and a pestle, then sieved using a 2.0 mm HACH Kit soil sieve assembly, Model SIW-1 (Hach, 1999). The powdered soil samples were analyzed for fertility parameters including: Nitrate nitrogen (NO_3-N), Phosphate (PO_4^-), Soil organic matter (SOM), alkalinity (pH), soil salinity denoted by Electric conductivity (EC) and total dissolved salts (TDS. The soil EC, pH and TDS were determined by using the aqueous extraction method at soil-water ratio (w:v) of 1:1 using the pH/EC/TDS/Temperature tester, Hanna Combo model HI 98129 (Hach Co. and Hach, 1992). The extraction of PO_4^- from the soil was done by using Mehlich 2 extractant at a soil-solution ratio (w: v) of 1:10 (Hach Co. and Hach, 1992).

The analysis of the available soil PO_4^- in the extract was achieved by the Phosphate-Phosver 3 method using the spectrophotometer, Hach DR 4000U (Hach, 1999). The extraction of soil NO_3-N from the soil was achieved by using the Calcium sulphate extraction method, at the soil-extractant ratio (w:w) of 100:1 (Hach Co. and Hach, 1992).

The analysis of NO_3-N in the extract was done by using the Nitrate-nitrogen-Nitraver V method using the Spectrophotometer, Hach DR 4000U (Hach, 1999). The soil organic matter (SOM) was determined according to the method described by Ridine *et al.* (2014).

Statistical data analysis: The determination of fertigation effects of treated wastewater on soil fertility parameters, growth and yield attributes of maize in field plots was achieved by using the one-way ANOVA at ($P \leq 0.05$) using INSTAT software.

Also, Pearson correlation analysis was run in MS Excel to determine the correlation of growth attributes and the maize yield.

RESULTS AND DISCUSSION

Irrigation water quality: The treated wastewater and tap water used for fertigation of maize plants were analyzed for physical and chemical parameters (Table 1). Treated wastewater was slightly alkaline with mean pH value of 7.8±0.2; Electrical conductivity (EC), 0.602.8±0.08 dS/m and Total dissolved salt (TDS), 301.5±39.1 mg/L. Chemical analysis showed that treated wastewater had biochemical oxygen demand (BOD_5) of 109.0±29.7 mg/L; Chemical Oxygen demand (COD), 77.0±36.0 mg/L; Sodium, 19.8±1.0 mg/L; Magnesium, 6.4±0.4 mg/L; Calcium, 17.8±4.2 mg/L; Nitrate, 2.0±1.1 mg/L; Phosphate, 37.5±4.5 mg/L and Sodium adsorption ratio (SAR), 1.022 Meq/L. The results on the trace heavy metals showed that iron (Fe), 0.4±0.1 mg/L; Copper (Cu), 0.01±0.0 mg/L; Lead (Pb), 0.2±0.1mg/L; Manganese (Mn), 0.1±0.0 mg/L; while Nickel (Ni) and Zinc (Zn) were below the detection limit. Similar parameters of tap water were lower compared to treated wastewater; except the average pH, 8.25±0.1; Sodium (Na), 42.2±1.3 mg/L; Magnesium (Mg), 32.3±3.1 mg/L; Calcium (Ca), 58.4±2.9 and Potassium (K), 29.1±1.6 mg/L. Assessment of nutrient contribution to the soil as irrigation water was performed for treated wastewater and revealed that at the annual application rate of 5000m^3/ha/year as in WHO and UNEP (2006), the nutrient contribution of the treated wastewater is 11.0 Kg/ha/year of NO_3-N, 172 Kg/ha/year of PO_4-P, 49.0 Kg/ha/year of Potassium (K) and 390 Kg/ha/year of organic matter.

Table 1. Constituents of treated wastewater and tap water used for irrigation of maize plants in the experimental plots. The nutrient contribution of this treated wastewater to maize plants may be partial or in full supply to some nutrient components depending on the yield potential of maize and soil nutrients content.

S/N	Parameters	Units	Irrigation water analyzed		FAO standards
			Treated wastewater	***Tap water***	
1	pH		7.6±0.15	8.2±0.18	6.0-9.0
2	EC	dS/m	0.612.8±0.13	0.48±0.12	0-2
3	TDS	mg/L	304.5±35.5	211.3±12.8	0-2000
4	Nitrate (NO_3-N)	mg/L	2.2±0.6	0.55±0.04	0-15
5	NH_3-N	mg/L	12.3±7.1	0.11±0.03	0-5
6	Nitrite (NO^-)	mg/L	0.02±0.01	0.01±0.002	
7	Phosphate (PO_4-P)	mg/L	34.5±2.3	1.6±0.8	
8	BOD_5	mg/L	78.0±34.2	12.1±2.4	0-30
9	COD	mg/L	103.0±26.3	34.5±2.5	0-90
10	Sodium (Na)	mg/L	19.8±1.0	42.2±1.3	
11	Magnesium (Mg)	mg/L	6.4±0.4	32.3±3.1	0.2
12	Calcium (Ca)	mg/L	17.8±4.2	58.4±2.9	
13	Potassium (K)	mg/L	9.8±3.6	29.1±1.6	
14	SAR	Meq/L	1.042	1.098	0-6
15	Copper (Cu)	mg/L	0.01±0.0	<0.001	0.2
16	Zinc (Zn)	mg/L	<0.001	<0.001	2.0
17	Lead (Pb)	mg/L	0.2±0.1	<0.001	2.0
18	Nickel (Ni)	mg/L	<0.001	<0.001	0.2
19	Manganese (Mn)	mg/L	0.1±0.0	<0.001	0.2

Effect of fertigation with treated wastewater on soil nutrient residues: Table 2 shows the results on the effects of irrigation with treated wastewater on the soil fertility parameters on the field maize plots. Irrigation with treated wastewater was observed to increase soil organic matter by 25.8% from 3.1±0.2% to 3.9±0.3%. The same observation was noted in plots irrigated with tap water in which the soil organic matter increased by 15.8% from 1.9±0.3% to 2.2±0.4%. Other soil fertility parameters PO_4^-, NO_3-N and K^+ were observed to decrease after irrigation with treated wastewater and tap water in the experimental plots. Soil PO_4^- decreased by 58.7% from 27.6±9.7 mg/l to 11.4±4.1 mg/l in soil irrigated with treated wastewater, while it decreased by 83.6% in soil irrigated with tap water from 40.2±15.2 mg/l to 6.6±1.4 mg/l. Soil NO_3-N was observed to decrease by 12.9% from 14.7±3.7 mg/l to 12.8±3.9 mg/l in the plots irrigated with treated wastewater. In soil irrigated with tap water NO_3-N decreased by 34.2% from 18.1±7.2 mg/l to 11.9±1.9 mg/l. Likewise, soil K^+ was observed to decrease by 30.9 % in plots irrigated with treated wastewater from 51.4±14.4 mg/l to 35.5±20.4 mg/l. In plots irrigated with tap water, K^+ decreased by 9.6% from 42.6±10.6 mg/l to 38.5±6.0 mg/l. The decreases of soil fertility parameters were statistically not significant ($P \geq 0.05$).

Table 2. Concentration of fertility parameters in the soil before and after irrigation

S/N	Soil fertility Parameters	SI Unit	Soil irrigated with treated wastewater		Soil irrigated with tap water	
			Before irrigation	*After irrigation*	*Before irrigation*	*After irrigation*
1	pH		8.3±0.5	8.5±0.2	8.0±0.3	8.2±0.1
2	EC	dS/m	0.51±0.13	0.62±0.12	0.35±0.05	0.39±0.1
3	TDS	mg/L	231.7±6	313.3±7	158.3±21.9	195.8±50.8
4	Potassium (K^+)	mg/L	51.4±14.4	35.5±20.4	42.6±10.6	38.5±6.0
5	Organic matter	%	3.1±0.2	3.9±0.3	1.9±0.3	2.2±0.4
6	Nitrate (NO_3-N)	mg/L	14.7±3.7	12.8±3.9	18.1±7.2	11.9±1.9
7	Phosphate (PO^{4-}	mg/L	27.6±9.7	11.4±4.1	40.2±15.2	6.6±1.4

Data are in Mean ± standard deviation (n = 6)

Soil alkalinity as denoted by pH was observed to increase slightly by 2.4% from 8.3±0.5 to 8.5±0.2 in the plots irrigated with treated wastewater; and almost similar changes was observed in soil irrigated with tap water, in which the soil pH increased by 2.5% from 8.0±0.3 to 8.2±0.1. Soil salinity as denoted by EC and TDS was observed to increase in treatment and control plots. In plots irrigated with treated wastewater EC increased by 21.5% from 0.51±0.1 to 0.62±0.1, while it increased by 11.4% from 0.35±0.05 to 0.39±0.1 in plots irrigated with tap water. Soil TDS increased by 35.2% in soil irrigated with treated wastewater from 231.7±6 to 313.3±7, likewise in soil irrigated with tap water TDS increased by 23.7% from 158.3±21.9 to 195.8±50.8.

Effect of treated wastewater on the growth attributes of maize plants: Heights of plants: The results on mean heights of plants from 21st to 56th days after planting (DAP) are presented in Table 3. The results show an increasing trend from the first to the end of monitoring day for all plants in the experimental plots (EP) and control sub-plots (CP). Results on specific sub-plots show that the mean plant heights for experimental plots were 99.6±10.3 cm, 102.7±17.2 cm and 76.6±13 cm for sub-plots EP_1, EP_2 and EP_3 respectively. While for control sub-plots the mean plant heights were 66±12.7 cm, 56.1±18.7 cm and 53.1±17.3 cm for sub-plots CP_1, CP_2 and CP_3 respectively.

Table 3. Average heights of maize plats for different monitoring days

Plots	Monitoring time (DAP)					
	21	28	35	42	49	56
EP_1	43.2±7.6	56.4±11.2	81.7±15.5	91.0±9.9	98.1±11.9	99.6±10.3
EP_2	38.6±10.8	49.6±15.3	65.4±24.7	81.6±21.7	98.1±15.4	102.7±17.2
EP_3	34.6±12.9	45.3±14.2	54.3±19.5	64.5±27.2	75.6±12.2	76.6±13
CP_1	19.1±5.3	21.7±5.6	30.3±8.3	41.7±11.7	59.5±19.2	66.7±12.7
CP_2	18.7±6.7	21.1±8.4	26.2±7.3	34.7±14	47.1±21.1	56.1±18.7
CP_3	16.0±8.9	22.6±8.8	27.8±14	35.4±20.5	44.5±18.9	53.1±17.4

EP: Experimental plots, CP: Control plots; 1,2,3: Number of plots

The overall mean increase rate of plat heights was 10.8±5.2 cm and 8.1±3.4 cm for experimental and control plots respectively. Furthermore, the overall mean height of plants at the 56th DAP was 93.0±14.3 cm for plants in experimental plots and 58.6±7.1 cm for plants in control plots. The values of overall mean plant heights indicate that plants in the experimental plots were more than 1.5 times taller than the plants in control plots. According to statistical data analysis the heights of plants in the experimental plots were significantly higher than the plant heights in the control plots (P = 0.0203).

Leaf Area Index: The results on the trend of LAI during the monitoring period is shown in Table 4. The results show an increasing trend of LAI from the 21st to the 56th DAP. During the 56th DAP the mean LAI for individual sub-plots in for individual experimental sub-plots were 144.9±32.1, 146.6±59.4 and 115.8±51.8 for sub-plots EP_1, EP_2 and EP_3 respectively. The results for control sub-plots were 62.7±22.4, 57±27.4 and 46.7±32.7 for sub-plots CP_1, CP_2 and CP_3 respectively. The overall increase rate of LAI was 24.8±22.6 for experimental plots and 12.2±6.3 for control plots. This indicates that the increase rate in LAI for plants in experimental plots was more than twice of plants in the control plots.

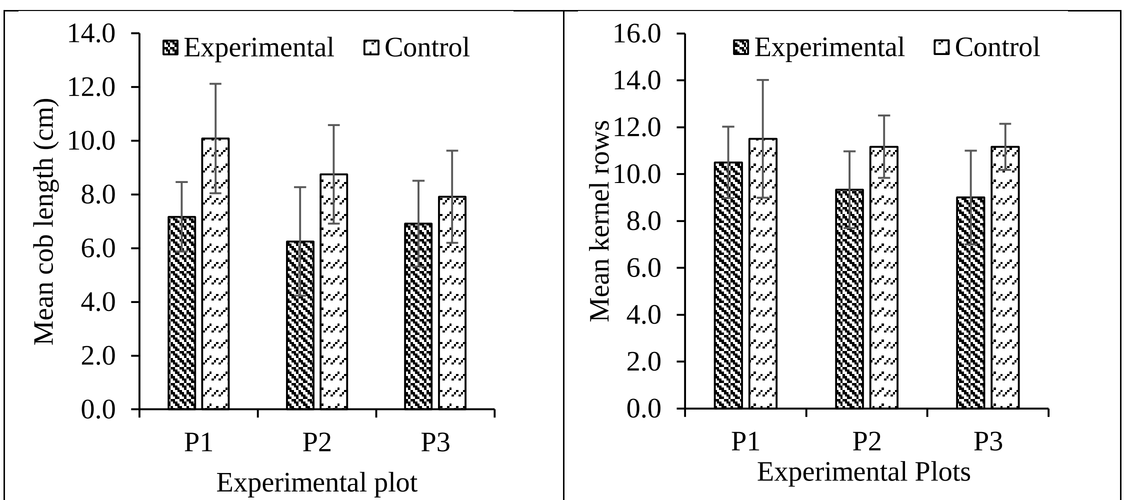
Table 4. Average Leaf area Index (LAI) of maize plats at different monitoring time

Plots	Monitoring time (DAP)					
	21	28	35	42	49	56
EP_1	75.3±34.2	139.4±46.8	171.4±46.0	151.6±36.8	147.6±56.2	144.9±32.1
EP_2	81.4±65.4	124.6±80.1	153.8±69.9	153.9±48.9	141.5±50.0	146.6±59.6
EP_3	71.4±44.9	98.7±61.9	124.9±60.5	120.8±49.2	117.2±52.8	115.8±51.8
CP_1	11.5±7.5	20.4±15.2	48.0±25.5	56.2±32.7	62.8±25.3	62.7±22.4
CP_2	10.9±8.7	17.1±13.0	32.8±25.9	52.9±28.2	48.1±31.2	57.0±27.4
CP_3	10.4±10.3	14.8±13.5	28.8±18.4	37.5±24.0	48.2±24.5	46.7±32.7

EP: Experimental plots, CP: Control plots; 1,2,3: Number of plots

The overall mean LAI at the 56th DAP was 135.8±17.3 for experimental plots, while it was 55.5±8.1 for control plots, indicating that the LAI for plants in the experimental plots was about 2.5 times than plants in the control plots. The statistical analysis showed that, the mean LAI for experimental plots was very significantly higher than that of the control plots (P = 0.0019).

Effect of treated wastewater on the yield attributes of maize: Cob length: The results on the average cob lengths are shown in Figure 1 (a). The results on the cob lengths for experimental sub-plots were 7.2±1.3 cm, 6.3±2 cm, and 6.9±1.6 cm for EP_1, EP_2 and EP_3 sub-plots respectively; while the lengths from the counterpart control sub-plots were 10.1±2 cm, 8.8±1.8 cm and 7.9±1.7 cm for CP_1, CP_2 and CP_3 respectively. The overall mean cob length was 6.8±0.5 cm for experimental plots and 8.9±1.1 cm for control plots. Statistical analysis revealed that the mean cob length from the experimental plots was significantly shorter than the mean value from control plots (P = 0.0367).

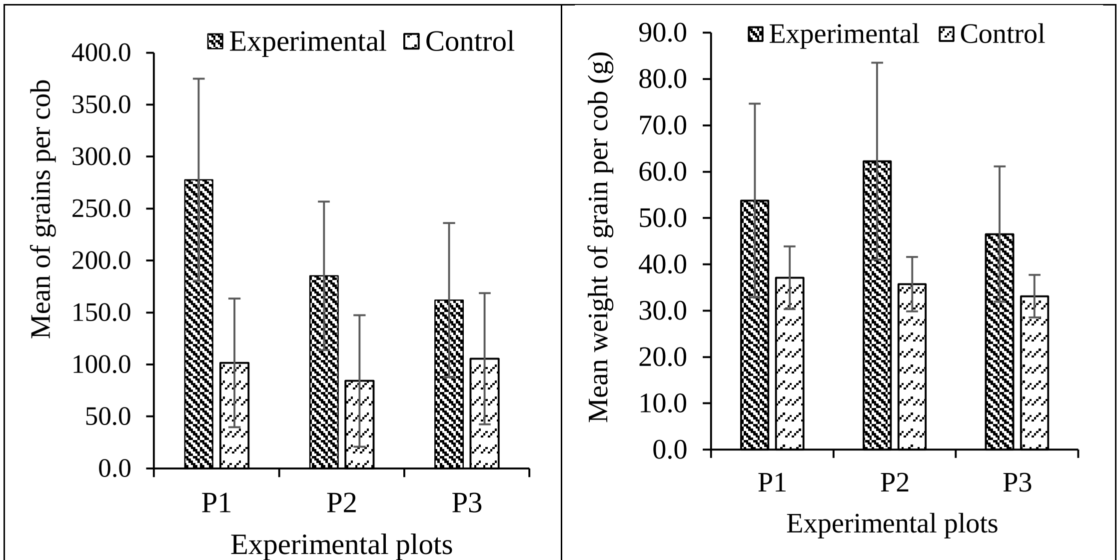


(a) Mean cob length (b) Mean kernel rows per cob

Fig 1. Mean cob length per plot and mean kernel rows per cob in the plots.

Number of kernel rows per cob: The numbers of kernel rows per cob were determined for the sampled cobs from each sub-plot and the results are shown in Figure 1 (b). The results showed that the mean number of kernel rows for cobs from the experimental sub-plots were 10.5±1.5, 9.3±1.6, and 9±2 for EP_1, EP_2 and EP_3 respectively. The results from the corresponding control sub-plots were 11.5±2.5, 11.2±1.3 and 11.2±1 for CP_1, CP_2 and CP_3 sub-plots respectively. The overall mean number of kernel rows for experimental plots was 9.6±0.8 while it was 11.3±0.2 for control plots, indicating higher mean number of kernel rows by 17.7% for control sub-plots than their corresponding experimental sub-plots. Statistical analysis revealed that the mean number of kernel rows from experimental plots was significantly lower than the control plots ($P = 0.0223$).

Number of grains per cob: The number of grains per cob was determined for sampled cobs and the mean number of grains per cob is presented in Figure 2 (a). The results show that the mean number of grains per cob from the experimental sub-plots were 277.7±97.1, 185±71.4 and 162±74.1 for sub-plots EP1, EP2 and EP3 respectively. The mean number of grains per cob from the corresponding control sub-plots, were 102±62, 84±63.4 and 106±63.1 for sub-plots CP1, CP2 and CP3 respectively. The overall mean number of grains per cob was 208±61.2 for experimental plots, while it was 97±11.3 for the control plots. The findings show that the mean number of grains per cob was higher in all experimental sub-plots when compared with the corresponding control sub-plots. Statistical analysis revealed that the mean number of grains per cob from experimental plots was significantly higher that the control plots ($P = 0.0363$).



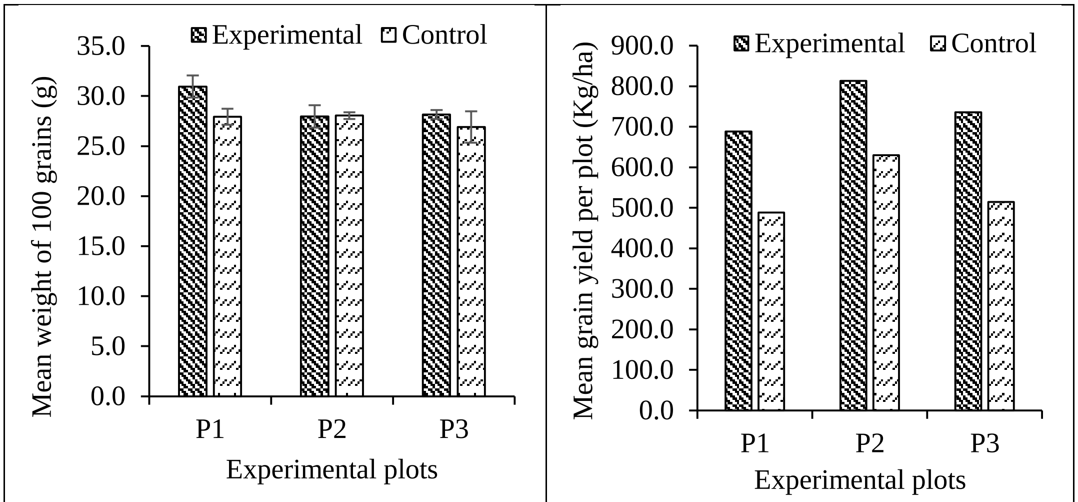
(a) Mean number grains per cob | (b) Mean weight of grains per cob

Fig 2. Average number and weight of grains per cob

Effect of irrigation with treated wastewater on the weight of grains per cob: Weights of grains per cob were measured to determine the quality of grains and the mean weights of grains per cob are shown in Figure 2 (b). Results show that the mean weights of grains per cob from the experimental sub-plots were: 53.8±20.9 g, 62.3±21.3 g and 46.5±14.6 g for EP_1, EP_2 and EP_3 sub-plots respectively. The mean weights of grains per cob from the counterpart control sub-plots were 37.1±6.8 g, 35.7±5.9 g and 33.1±4.6 g for sub-plots CP_1, CP_2 and CP_3 respectively. The overall mean weight of grains per cob was 80.7±7.9 g and 35.3±2.0 for experimental and control plots respectively. The results show that the mean weight of grains per cob was more than 2 times higher for cobs from experimental plots than the corresponding control plots. Statistical analysis revealed that the mean weight of grains per cob from the experimental plots was significantly greater than the control plots ($P = 0.0160$).

Mass of 100 grains: Weights of 100 maize grains were measured to compare the quality of grains from experimental and control plots and the results are presented in Figure 3 (a). The mean weights of 100 grains from experimental sub-plots were 37.9±1.1 g, 36.0±1.1 g and 31.2±0.4 g for EP_1, EP_2 and EP_3 sub-plots respectively. The results from the corresponding control sub-plots were 27.9±0.8 g, 28.0±0.3 g and 26.0±1.6 g for CP_1, CP_2 and CP_3 respectively. The overall mean weight of 100 grains was 35.0±3.5 g and 27.6±0.6 g for experimental and control plots respectively.

Grain yield: The weight of all grains per plot was measured to determine the grain yield per hectare from the experimental and control sub-plots as shown in Figure 3 (b).



(a) Mean weight of 100-grains per cob | (b) Mean grain yield per plot

Fig 3. Mean weight of 100-grains per cob and grain yield per plot
The mean weight of 100 grains from experimental plots was 26.8% higher than their counterpart control plots. The results of statistical analysis revealed that the mean weight of 100 grains from experimental plots was significantly greater than that of the control plots (P = 0.0214).

Results on grain yield from the experimental sub-plots were 688.7 Kg/ha, 813.2 Kg/ha and 735.4 Kg/ha for sub-plots EP_1, EP_2 and EP_3 respectively. The grain yield from the corresponding control sup-plots were 488.8 Kg/ha, 630.0 Kg/ha and 514.8 Kg/ha for sub-plots CP_1, CP_2 and CP_3 respectively. The overall mean grain yield was 745.8±62.9 Kg/ha and 544.5±75.1 Kg/ha for experimental and control plots respectively. The results show that the yield from experimental plots was about 37% higher than the yield from the control plots. The results of statistical analysis revealed that the mean grain yield from experimental plots was significantly greater than that of the control plots (P = 0.0237).

Quality of irrigation water: The analysis results of treated wastewater revealed that Nitrate-nitrogen, Ammonium-nitrogen, Potassium and Phosphorous were higher in treated wastewater than in tap water which are essential nutrients for soil fertility and plant growth. Their higher concentrations in treated wastewater than in tap water was an important factor attributed to the observed higher growth and yield attributes of maize plants irrigated with treated wastewater. Values of BOD, COD and TD concentration were higher in treated wastewater than in tap water. According to WHO and UNEP, (2006), BOD contributes to soil organic matter content which enrich the soil with humic content. The humic content increases soil moisture content, improves retention of metals, enhance soil microbial activity, influence water absorption by the plants and formation of organometallic contents which are important in improving the growth and yield components of plants (Urbano *et al.,* 2017). The concentrations of nutrients including Nitrate (NO_3-N), NH_3-N, Nitrite (NO^-) and Phosphate (PO4-P) were higher in treated wastewater than in trap water which supplemented the soil nutrients for improving plant growth and yield (Bame *et al.,* 2014). Other parameters, including micro-nutrients and heavy metals concentrations in the treated wastewater and tap water were lower than the acceptable standard values prescribed by WHO and UNEP (2006) for wastewater reuse in irrigation.

Effect of fertigation with treated wastewater on soil nutrient residues: As reported in section 3.2 the soil organic matter was observed to increase in plots irrigated with treated wastewater and tap water; the increase was more pronounced in plots irrigated with treated wastewater. The increase in soil organic matter is attributed to the concentrations of BOD_5 and COD in treated wastewater used for irrigation (Adejumobi *et al.,* 2014; Tsigoida and Argyrokastritis, 2019; Elamin *et al.,* 2020). However, the concentrations of BOD_5 and COD in treated wastewater and type of soil determine the extent of change of the soil organic matter (Alves *et al.,* 2019; Salgado-Méndez *et al.,* 2019 ; Dhakshanamoorthy Dinesh *et al.,* 2021). In addition to treated wastewater, also plant residues after harvesting contribute to soil organic matter as denoted in soil irrigated with tap water. Soil organic matter improves the ability of soil to hold water, produce essential nutrients on decomposition and improves the soil aggregate stability (Adejumobi *et al.,* 2014), all of which influence plant growth and yield. On the contrary, soil essential nutrients namely PO_4^-, NO_3-N and K^+ were observed to decrease after harvesting of maize in all plots irrigated with treated wastewater and tap water. The decrease of soil nutrients could be attributed to various factors including uptake by maize plants, leaching below the root zone enhanced by percolation of rain water and washout from the soil surface by runoff as a result of three rainfall events recorded during the experimental period (Disciglio *et al.,* 2015). The decrease of NO_3-N could be further be aggravated by volatilization (Veizaga *et al.,* 2016). However, the decrease of nutrients (PO_4^-, and NO_3-N) was more pronounced in plots irrigated with tap water than plots irrigated with treated wastewater, which indicates the influence on treated wastewater on supplementing the soil nutrients. Soil salinity parameters (EC and TDS) and alkalinity (pH) increased after harvesting which is associated with addition of basic cations (Mg and Ca) and exchangeable sodium in the soil by the irrigation water (Disciglio *et al.,* 2015).

Effect of treated wastewater on growth attributes of maize plants: Growth attributes of maize plants including plant height, leaf length, number of leaves and LAI were influenced with fertigation with treated wastewater from the digester coupled with anaerobic baffled reactor (ABR). It was observed that plant height and LAI of maize plants in plots fertigated with treated wastewater were significantly higher ($P \leq 0.05$) at all observation time periods. The improvement of growth attributes of maize plants may be associated with the nutrient supplements and organic matter added to the soil by treated wastewater (Bame *et al.,* 2014; Balengayabo *et al.,* 2022). The fertigation with treated wastewater provided essential nutrients and organic matter as presented in section 3.1, which supplemented the oil nutrients to supply relatively adequate quantity of essential nutrients responsible for the observed improvements in the growth attributes of maize plant (Bame *et al.,* 2014; D. Dinesh *et al.,* 2021). The findings are in line with previous studies using treated wastewater from different sources and treatment technologies. The study by Ku *et al.,* (2021) revealed significant improvement in growth attributes for maize fertigated with effluent from beverage industry; Dinesh *et al.,* (2021) found improved growth attributes for maize fertigated with effluent from distillery industry in India. The study by Khan *et al.,* (2012) in Pakistan reported significantly improved growth attributes of millet plants (plant height, number of leaves per plant and leaf area) for plants irrigated with effluents from waste stabilization ponds. Other findings by Nyomora, (2015) in Tanzania showed improved growth attributes of rice irrigated with effluent from waste stabilization ponds. The nutrients and organic matter in the treated wastewater have been cited to influence the improvements in plant growth and development. This may further be supported by the observed soil nutrient residues in section 3.2 which were relatively higher in plots fertigated with treated wastewater as compared to plots irrigated with tap water.

Effect of treated wastewater on yield attributes of maize: The results revealed that fertigation with treated wastewater significantly increased maize yield in experimental plots as compared to control plots, which implies that fertigation with treated wastewater from the anaerobic digester coupled with ABR improved maize yields. With exception of cob length and number of kernel rows per cob, other yield attributes including number of grains per cob, weight of grains per cob, mass of 100 grains and grain yield were significantly higher ($P \leq 0.05$) in plots fertigated with treated wastewater as compared to those irrigated with tap water. Improvement of soil fertility parameters as results of fertigation with treated wastewater may cited for the observed differences in growth and yield in the plots fertigated with treated wastewater. Fertigation, with treated wastewater supplement the soil with nutrients and organic matter needed by plants for growth and yield as evidenced by nutrient residues in the soil after harvesting in section 3.2 (Bame *et al.,* 2014; Kihila *et al.,* 2014; Balengayabo *et al.,* 2022). Improved growth attributes especially LAI denotes improved photosynthetic capacity of plants responsible for production of food that is used for production of maize grains as storage organs. Pearson correlation analysis revealed that grain yield was strongly correlated with plant height ($r = 0.764$) and LAI ($r = 0.854$), implying that plants with better growth attributes are more likely to produce more yields. This was apparently evident since plants with better growth attributes in plots fertigated with treated wastewater yielded more than control plots irrigated with tap water. Similar findings were reported by Dinesh *et al.,* (2021); Ku et *al.,* (2021) and Kokkora *et al.,* (2015), where the yield attributes of maize were higher in plots irrigated with treated wastewater. Cob length and number of kernel rows per cob which were higher in plots irrigated with tap water simply denote the quantity but in terms of yield attributes denoting the quality of grains such as weight of grains per cob, mass of 100 grains and grain yield were significantly higher ($P \leq 0.05$) in plots irrigated with treated wastewater. Therefore, application of treated wastewater for fertigation to plants is beneficial as it supplements the soil nutrients for growth and yield crops.

Conclusion: Fertigation with treated wastewater from anaerobic digester coupled with ABR in series improved soil nutrient residues as indicators of soil fertility after harvesting, particularly the soil organic matter and soil Phosphate with no significant effect ($P \geq 0.05$) on soil alkalinity and salinity. The growth and yield attributes of maize in plots fertigated with treated wastewater were significantly improved ($P \geq 0.05$) evidencing the effects of fertigation with treated wastewater from anaerobic digester coupled with ABR in series on the improved soil fertility.

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