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Research article

Partially treated domestic wastewater as a nutrient source for tomatoes (*Lycopersicum solanum*) grown in a hydroponic system: effect on nutrient absorption and yield

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A B S T R A C T

Using effluent from the anaerobic baffled reactor (ABR) of the decentralised wastewater treatment system (DEWATS) as a sole nutrient source is not sufficient for tomato plants grown in hydroponic system. The study investigated the effects of commercial hydroponic fertilizer mix (CHFM) combined with ABR effluent on tomato growth and yield. A media-based hydroponic technique consisting of three treatments, namely, ABR effluent, CHFM, and ABR effluent combined with CHFM (ABR + CHFM (50:50 v/v) was used. The results showed that plant growth parameters, biomass, fruit yield and shoot nutrient content were significantly higher in tomato plants fed with CHFM and ABR + CHFM than those grown in ABR effluent. Addition of 50 % dose of CHFM in ABR wastewater (ABR + CHFM) increased shoot N, K, Ca and Zn. These results indicated that adding 50% CHFM can alleviate nutrient deficiencies when partially treated wastewater from anaerobic digester is used as a nutrient source for hydroponic tomato cultivation.

1. Introduction

Wastewater hydroponic system is the integration of wastewater treatment into hydroponic plant production (Norström et al., 2003). In a wastewater hydroponic system, nutrients generated from wastewater treatment through physical and microbial degradation are absorbed by plants. Using such synergies offer several advantages over other bioremediation/phytoremediation techniques such as constructed wetlands by producing value-added crops (Roosta and Hamidpour, 2011). As a wastewater-based hydroponic technology, it requires less area, it is inexpensive and can be implemented onsite (Norstrom et al., 2003). The hydroponic component serves as a secondary or tertiary treatment step for wastewater treatment thus minimizing the requirements for further purification of wastewater to levels acceptable for disposal standards. Hence, linking the two systems may offer sustainable options in which renewable resources such as water and nutrients recovered from domestic wastewater can be used for crop production. This will reduce energy and input costs (fertilizer and irrigation) which are commonly involved in conventional wastewater treatment plants and commercial hydroponic crop production systems, respectively (Azad et al., 2013).

The use of wastewater effluents as nutrient sources for hydroponic crop production has been widely used as a form of domestic wastewater disposal (Yang et al., 2015; Oyama et al., 2005; Haddad et al., 2011). This practice has been recognised as one of the sustainable methods for wastewater management. Several studies have shown the potential of different types of wastewater as a source of fertilizer and irrigation water for the cultivation of green plants in the hydroponic system (Rabbabah and Ashbolt, 2000; Khan et al., 2011; Monnet et al., 2002; Power and Jones, 2016). In these studies, a number of crop species, including leafy vegetables (lettuce, spinach and silver beets), fruit crops (tomatoes, eggplant and pepper) and ornamental plants (*e.g.* rose bushes and carnations) grown in hydroponic system have been reported to be suitable

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for wastewater hydroponic system. Results from these studies showed variation in nutrients (nitrogen and phosphorus) removal, yield/biomass production and crop quality when compared to either conventional wastewater treatment or commercial hydroponic crop production system (Haddad et al., 2011). This variation is caused by a number of factors including, crop selection in terms of adaptability to grow in hydroponic systems and their tolerance to grow under wastewater of different qualities, the source and composition of wastewater used for agricultural irrigation and fertilization (Magwaza et al., 2020a). The method of wastewater treatment before reuse is also reported to have an effect on crop performance irrigated with wastewater.

Decentralised wastewater treatment systems (DEWATS) which involve the combination of treatment and disposal of wastewater has gained attention in recent years (Massoud et al., 2009). Such an approach allows for the reuse of treated wastewater within the source of generation and is designed to operate at a small-scale level, thereby offering sustainable opportunities for wastewater treatment especially for developing countries (Green and Ho, 2005). This system involves a number of treatment stages/processes for the breakdown of waste fractions in a wastewater treatment plant. Among those processes, anaerobic digestion is regarded as the most important component of the DEWATS system due to its low requirement on energy inputs, low sludge production and the opportunity to recover nutrients (N and P) from the effluents produced (Tauseef et al., 2013). This high nutrient load of wastewater generated through anaerobic digestion has prompted its use for agriculture, including the hydroponic cultivation of crops.

Generally, higher plants require both macro and micronutrients to grow and reproduce to their full potential. The most essential elements required in sufficient amounts for tomato cultivation include, N, P, K, Ca, Mg, Fe, Zn. The demand for these nutrients is known to be higher in hydroponically grown crops compared to their field-grown counterparts. This is because field produced crops source a portion of their nutrients supply from the soil, whereas, in hydroponic production system, the nutrient requirements of the crop are fulfilled by the nutrient solution (Stewart et al., 2005). Integrated wastewater treatment and hydroponic plant production systems that solely depend on wastewater to supply nutrients for tomato plants have been reported to be deficient in nutrients such as nitrogen, phosphorus, potassium and calcium (Roosta and Hamidpour, 2011). This is attributed to the low content of nutrients such as N, P, K, Ca and Mg in wastewater effluents. In addition, the complex nature of tomato plants in terms of nutrient management which is highly variable than leafy vegetables are also known to be the limiting factor for growth and yield performance in wastewater hydroponic systems. The nutrient demand of tomatoes changes as the plants grow from germination, vegetative to the reproductive stage (Nelson, 2008). From germination to first flower development, N, P, K are the most critical nutrients required by the plants while, K, Ca, Mg, Zn and Mn are required in sufficient amounts during fruit set.

Most investigations have shown that the plant nitrogen content decreased significantly when digestates from organic manure were used as an alternative to mineral fertilizers under hydroponic systems (Liu et al., 2009), as well as in pot experiments (Losak et al., 2011). The reduction in N content has been related to differences in the composition of the digestate. However, NH_4^+ is known to be the dominant source of N for domestic wastewater hence its conversion to nitrate is required for hydroponically grown tomatoes (Liedl et al., 2004: Liedl et al., 2006). This is necessary because of the high sensitivity of tomatoes to high NH_4^+–N levels. The low content and unavailability of Mg and P in wastewater effluents as a result of struvite formation and precipitation during anaerobic digestion were also reported to be the growth-limiting factor for hydroponically grown tomatoes (Liedl et al., 2004; Magwaza et al., 2020b, 2020c; Phoku et al., 2020). However, other studies have reported that supplementation of wastewater with deficient nutrients improved plant growth in hydroponically grown plants. The addition of P and micronutrients particularly, iron increased the shoot biomass of lettuce (Liu et al., 2011). Such practice created a balance between N: P ratio and improved Fe availability (Liu et al., 2011). Moreover, the addition of commercial hydroponic fertilizer mix into municipal wastewater has been reported to result in high yield gains on field-grown tomatoes (Khan et al., 2011). Their findings further indicated that using fertilizer supplemented wastewater did not increase the level of heavy metal in the leaves of tomato plants.

A similar observation was reported when the effect of foliar application of nutrients such as Mn, Fe, Mg, Zn, Cu, K, Mg was investigated on tomato plants grown in aquaponics (Roosta and Hamidpour, 2011). Hence, optimizing tomato production in hydroponic systems may require the addition of fertilizer to wastewater if used as nutrient sources. However, little information is available about the effects of combining domestic wastewater with commercial hydroponic fertilizer mix on hydroponically grown tomatoes. Therefore, the aim of the study was to investigate the combined effect of domestic wastewater and commercial hydroponic fertilizer mix as plant nutrient sources on growth and yield performance and nutrient availability of hydroponically grown tomatoes.

2. Materials and methods

2.1. Hydroponic system design

The hydroponic system used for this study was developed based on the design by Norström et al. (2003) and Sibanda et al. (2019) and was located at Newlands Mashu Research Station, Durban in South Africa. The system consisted of three individual hydroponic systems, each system consisted of one nutrient solution tank (100 L), a submersible pump, a filter and plant growth bed unit of 15 m × 0.5 m x 0.9 m in length, width and height), respectively (Figure 1). A storage tank, which was located between the growing tunnel and the sewage treatment plant, supplied wastewater effluents to the water holding tanks. The nutrient solution was continuously delivered from the tanks to the growth beds using a submersible pump and the water was recirculated back to the tank, located at the foot of the system. The nutrient solution was supplied to the plants via fertigation using a drip irrigation system (2 L/hour) and irrigation was performed at six intervals (5 min per interval) daily using a timer.

2.2. Nutrient sources

The wastewater used was collected from the exit of a wastewater treatment system (DEWATS), which is installed opposite the plant growth tunnel. The treatment system is composed of five treatment stages including (septic tank, anaerobic baffled reactor, anaerobic filtration, horizontal and vertical wetlands) used for the treatment of wastewater. The anaerobic baffled reactor is a primary treatment stage responsible for anaerobic decomposition of wastewater producing nutrient-rich effluents.

The commercial fertilizer mix was prepared by mixing hydroponic fertilizer mixture (Hygroponic® and Solucal®) with municipal tap water at the rate of 0.8 kg + 6.2 kg/1000 L of water as recommended for hydroponic tomato production. The ABR + CHFM treatment was prepared by mixing half a dose of CHFM with ABR effluents. No water was added; only wastewater was used to irrigate plants for the ABR effluents and ABR + CHFM treatment. Table 1, summarizes the physicochemical characteristics and chemical composition of the nutrient solutions used for the three hydroponic units consisting of ABR effluent, ABR + CHFM and CHFM treatments.

2.3. Plant growth trial and experimental procedures

Two weeks old tomato seedlings of a determinate cultivar ("Monica"), were transplanted into planting pots (7 cm diameter and 15 cm height) filled with pine shavings. The plants were grown in a polyethylene tunnel from March to June 2019. The average minimum and maximum temperature in the growing tunnel was 13 and 34 °C, respectively. Daily and

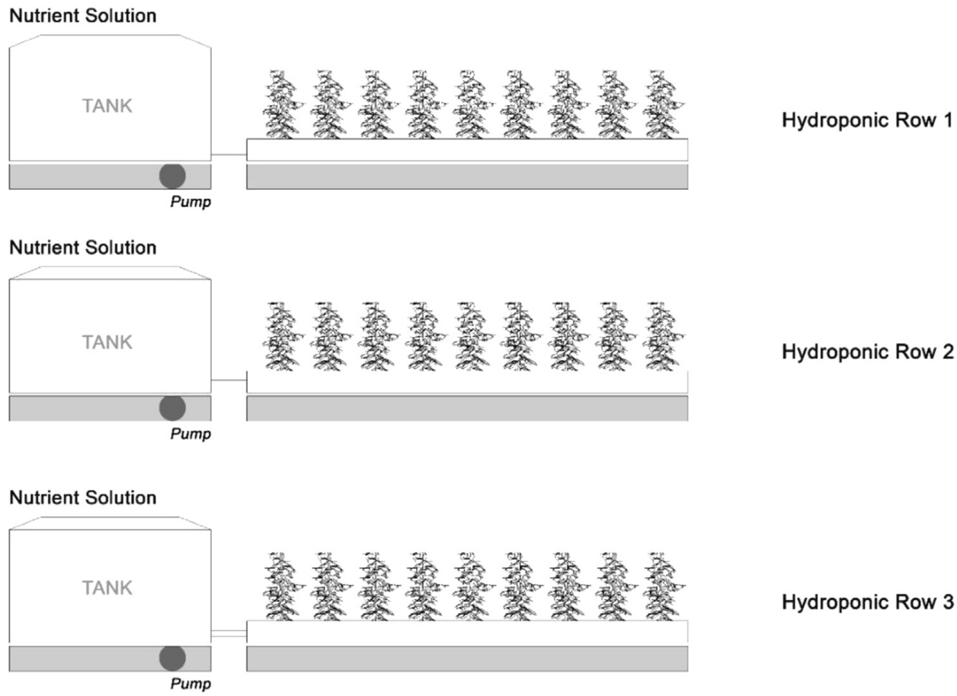

Figure 1. Schematic illustration of hydroponic wastewater system.

night relative humidity was between 76 and 82 %, respectively. The experimental pots were arranged in a complete randomised with three treatments viz., municipal tap water mixed with commercial hydroponic fertilizer mix, which consists of Hygroponic® and Solucal®, at the rate of 80 g and 62 g/100 L respectively (CHFM), wastewater effluents from anaerobic baffled reactor without fertilizer (ABR effluents) and wastewater effluents plus half dose of commercial hydroponic fertilizer mix at a rate of 40 g and 31 g per 100 L of water (ABR + CHFM). The chemical fertilizer mix (CHFM) was used as a control for the experiment. The experimental treatments were replicated three times. The nutrient solutions were changed every two weeks for plants at an early development stage and subsequently every week at a mature growth stage. Tomato plants were trellised along overhead wires, and the fruits were harvested every week from 72 to 106 days after transplanting.

2.4. Chemical analysis for nutrient solutions

Water samples from the nutrient solutions were collected and analysed for the following chemical quality parameters; pH, electrical conductivity (EC), dissolved oxygen (DO), total soluble solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonium-nitrogen (NH_4^+-N), Nitrate-nitrogen (NO_3^- - N) and Phosphorus (PO_4^{-3}), calcium (Ca), iron (Fe), copper (Cu), magnesium (Mg), manganese (Mn), zinc (Zn) and sulphur (S). Both influent and effluent

Table 1. Physico-chemical characteristics and chemical composition of the selected nutrient solutions (n = 9).

Parameter (mg/l)	ABR effluent	CHFM	ABR + CHFM
Nitrate-N	0.74 ± 0.08	63.4 ± 1.10	27.6 ± 1.84
Ammonium-N	24 ± 2.82	5.30 ± 0.75	38.0 ± 2.62
Total phosphorus	5.46 ± 0.73	9.47 ± 0.76	13.4 ± 1.90
Potassium	17.2 ± 0.96	63 ± 4.30	69.0 ± 4.16
Calcium	24 ± 2.37	52 ± 4.20	47.0 ± 1.37
Magnesium	10.8 ± 1.20	13.8 ± 1.48	17.5 ± 2.12
Sulphur	15.0 ± 1.41	20 ± 2.83	33.0 ± 2.82
Iron	135.0 ± 14.00	100 ± 8.06	191 ± 12.64
Manganese	41.0 ± 2.67	42.0 ± 1.46	72.0 ± 3.96
Sodium	109.0 ± 12.02	17.0 2.26	130.0 ± 13.4
Copper	15.9 ± 1.48	16.6 ± 1.44	61.0 ± 4.24
Zinc	15.7 ± 2.77	41.0 ± 7.14	65.0 ± 4.24
BOD	18.0 ± 1.41	10.0 ± 1.56	11.0 ± 1.41
COD	127.0 ± 7.78	24.0 ± 2.12	135.0 ± 2.83
DO	3.2 ± 0.06	3.4 ± 0.08	3.3 ± 0.07
TSS	18 ± 1.41	12 ± 1.41	11 ± 1.41
EC	799 ± 15.56	1531 ± 13.44	1532 ± 14.14
pH	7.86 ± 0.16	6.93 ± 0.05	7.77 ± 0.04

ABR, anaerobic baffled reactor; CHFM, chemical hydroponic fertilizer mix; ABR + CHFM, commercial hydroponic fertilizer mix added to effluent; BOD, biochemical oxygen demand; COD, chemical oxygen demand; DO, dissolved oxygen; TSS, total soluble solids; EC, electrical conductivity.

samples were collected for each hydroponic unit, and the samples were stored at −20 °C and later sent to Talbot Laboratories (Pty) Ltd for analysis. Measurements on levels of pH and EC were taken on a daily basis and no adjustments were made to stabilize the nutrient solutions in the hydroponic system.

2.5. Plant growth measurements

2.5.1. Chlorophyll content index

The plant leaf chlorophyll content from the newly expanded leaf was measured with a portable chlorophyll meter (SPAD-502, Minolta Corp., Ramsey, NJ, USA). The measurements were taken based on the growth stage of the plants (seedling, vegetative and reproductive stage). A sample of five plants per each replicate was used to detect the leaf chlorophyll content and the average values were used to present the SPAD values.

2.5.2. Leaf area index

LAI-2200 Plant canopy analyser (LI-COR, Lincoln, NE, USA) was used to measure leaf area index (LAI) of the plants. The instrument is comprised of a measurement wand, attached to a control unit, and a fish-eye optical sensor. The measurement of leaf area index using LAI 2200 involves the measurement of both above canopy readings, and below canopy readings to measure the total incoming light and the capturing of the incoming light, respectively. The view cap was placed at an angle of 270°, according to Danner et al. (2015) to avoid any interruptions that might cause inaccuracies during the operation. All measurements were taken under overcasting conditions before 9:00 am to avoid direct sunlight.

2.5.3. Photosynthetic rate

LI-6400 XT Portable Photosynthesis System (LI-COR Bioscience, Lincoln, Nebraska, USA) was used to measure the rate of Photosynthesis (A) for the plants. The artificial saturating photosynthetic active radiation (PAR) was set at 1000 μmol m^{-2} using the leaf chamber fluorimeter (6400-04B, LI-COR Biosciences, Lincoln, Nebraska, USA) and ambient carbon dioxide concentration (C_a) was adjusted to 400 μmol mol^{-1} using CO_2 injection (6400-01, LI-COR Biosciences, Lincoln, NE, USA). The flow rate of water and relative humidity were maintained at 500 μmol s^{-1} and 43%, respectively. A representative of five plants per each replicate were used, and the third half-fully expanded leaf was selected. A was detected by clamping the tip of the leaf inside the sensor head. Leaf measurements were taken around 12 and 14 PM, during sunny days.

2.5.4. Plant growth and biomass measurement

Plant growth measurements such as plant height, number of stems per plant and stem thickness were taken during the growth period based on the age of the plants. The height of the plant was taken by measuring the length of the plant from the base of the stem to the tip of the stem using a measuring tape. Stem thickness was measured using a calliper and the number of stems were counted for each plant. At the end of the trial (106 days after transplanting), above-ground biomass, fresh weight (SFW) and dry weight (SDW) of the shoot were weighed and oven-dried at 72 °C for 72 h. Fruit yield indicators in terms of fruit number, individual fruit mass per tree and overall fruit yield were also recorded.

2.5.5. Shoot mineral analysis (macro and microelements)

Macronutrients (N, P, K, Mg and Ca) and micronutrients (Fe, Zn,Mn, Cu, and Na) of tomato plant shoots were analysed. After harvesting, the plant shoots were harvested by cutting the plant at 1 cm above soil level and oven dried at 70 °C until they achieved constant weight. Prior to the analysis, samples were ground and sieved through a 0.84 mm sieve. The samples were taken to the Soil Fertility and Analytical Services Laboratory, CEDARA (KZN Department of Agriculture and Environmental Affairs) for analysis of leaf mineral content.

2.5.6. Statistical analyses

Data on plant growth, biomass and yield production and tissue mineral content were subjected to a one-way analysis of variance (ANOVA) using Genstat version 18 (VSN International, Hemel Hempstead, UK). Mean values among the nutrient sources were separated using Fischer's Least Significant Difference (LSD) test at 5 % level of significance.

3. Results and discussion

3.1. Effect of nutrient sources on tomato growth performance

Results from the study showed significant ($P < 0.05$) differences in plant height between plants grown in the three studied nutrient solutions. However, throughout the experiments, the nutrient solutions had no significant ($P < 0.05$) effect on stem diameter. The average plant height for the nutrient solutions used for this study with their respective growth stages of the plant was 22.56 cm $plant^{-1}$, 28.47 cm $plant^{-1}$ and 54 cm $plant^{-1}$ for seedling, vegetative and harvest stage respectively (Table 2). Plants fed with ABR effluents reported the shortest plant height compared to their CHFM and CHFM + ABR counterparts. Tomato plants fed with CHFM + ABR effluents showed increased plant height compared to CHFM and ABR for all the growth stages of the plants.

Table 2. Mean plant height (PH), leaf area index (LAI), stem diameter (SM), number of stems, chlorophyll content index (CCI) and photosynthetic rate (A) of tomato plants grown in various nutrient solutions. Measurements were taken at three growth stages (seedling, vegetative and harvest stage) n = 15.

Nutrient solution	PH (cm)	LAI	SD (mm)	No of stems	CCI	A
Seedling stage						
ABR effluents	20.57^a	0.703^a	3.70^a	1.0^a	36.54^b	28.79^a
CHFM + ABR	25.17^b	1.729^c	3.77^a	1.0^a	41.76^c	28.76^a
CHFM	21.93^a	1.218^b	3.88^a	1.0^a	29.30^a	31.10^a
Vegetative stage						
ABR effluents	25.80^a	0.963^a	4.23^a	1.0^a	40.67^b	29.49^a
CHFM + ABR	31.33^C	2.148^c	4.84^a	2.0^a	34.30^a	32.10^a
CHFM	28.27^b	1.600^b	5.16^a	2.0^a	40.21^b	32.89^a
Harvest stage						
ABR effluents	50.33^a	1.44^a	7.59^a	2.4^a	33.67^b	21.62^a
CHFM + ABR	58.80^c	3.22^c	8.32^a	3.0^b	29.30^a	28.17^a
CHFM	55.27^b	2.40^b	12.75^a	4.2^c	30.21^b	26.74^a

ABR, anaerobic baffled reactor; CHFM, commercial hydroponic fertilizer mix; PH, plant height; LAI, leaf area index; SD, stem diameter, CCI; chlorophyll content index; A; photosynthetic rate. Columns sharing the same letter are not significantly different at P of 0.05.

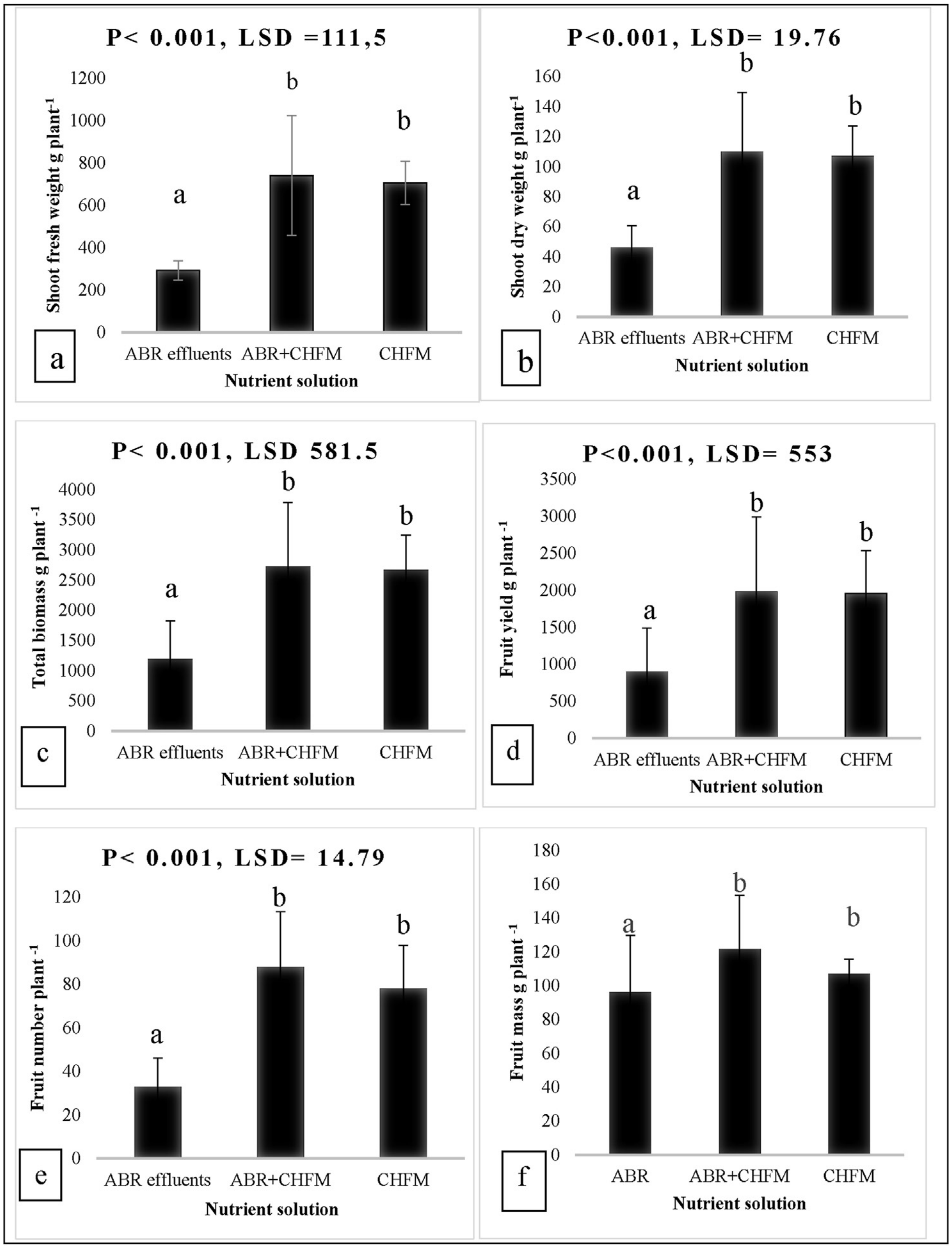

Figure 2. Shoot fresh weight per plant, b) shoot dry weight per plant, c) total biomass per plant, d) fruit yield per plant, e) fruit number per plant and f) fruit mass per plant. Columns sharing the same letter are not significantly different at P < 0.05.

In the case of leaf area index, significant ($P < 0.05$) differences were reported between the nutrient solutions across all the growth stages. Average LAI of 1.22, 1.57, 2.36 for seedling, vegetative and harvest stage, respectively, was observed. The plants exhibited a similar pattern for all the nutrient solutions used for this study, except at the seedling stage where there were significant (P < 0.05) differences between ABR effluents and CHFM treatment. The differential response in plant growth performances among the treatments is associated with the varying supply of nutrients contained in the nutrient solutions used to grow tomatoes in the study (Table 1). The reduction in the growth of plants in the ABR effluent treatment is attributed to the lower concentrations of nutrients essential for the development of tomato plants, especially nitrogen, phosphorus and potassium and calcium (Roosta and Hamidpour, 2011). However, the addition of 50 % commercial fertilizer in wastewater increased the plant height of tomato plants by 4.23 and 1.59 % more than the ABR effluent and CHFM treatment, respectively.

Similarly, LAI was also increased by 26 and 13 % more than the ABR and CHFM treatment, respectively. These results suggest that increasing the concentration of nutrients positively affected the growth of tomato plants. The increased levels of N, P, K, Mg, Ca and other micronutrients in the ABR + CHFM treatment were responsible for enhanced growth. Increasing the level of potassium and Nitrate-N which is lacking in wastewater effluents is reported to contribute to dry matter accumulation of plants thereby increasing plant growth. These findings correspond with the results of Roosta and Hamidpour (2011) who reported that the addition of K through foliar application increased the growth of tomato plants in aquaponics. Similar findings were reported by Kaya et al. (2001), who reported that foliar application of K increased dry matter accumulation in plants. Findings by Almeselmani et al. (2010) also showed that increasing the concentration of potassium in a nutrient solution improved the growth performance of tomatoes grown in hydroponics.

Table 3. Mean leaf nutrient content of tomato plants grown in a nutrient solution consisting of various nutrient composition and commercial hydroponic fertilizer mix. Leaves used for nutrient analysis were harvested on the last day of the experiment.

Nutrient sources	Macronutrients (mg/g)					Micronutrients (mg/kg)				
	N	P	K	Mg	Ca	Fe	Zn	Cu	Mn	Na
ABR effluents	28.8^{a}	4.3^{a}	9.1^{a}	9.3^{c}	24.8^{a}	216^{b}	44^{a}	945.5^{c}	217.0^{b}	6992.7
ABR + CHFM	34.8^{b}	5.8^{a}	37.7^{b}	8.1^{b}	33.6^{b}	224^{b}	81^{b}	631.0^{b}	201.0 ^{ab}	7371.7
CHFM	38.2^{c}	6.3^{b}	45.6^{c}	6.9^{a}	35.4^{b}	161^{a}	70^{b}	389.7^{a}	166.0^{a}	2496.8
P- Value	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.05	0.001
LSD	0.296	0.069	0.325	0.08	0.477	27.4	15.3	197.72	38.0	0.069
CV %	11.4	16.6	13.6	12.9	17.8	18.0	30.7	39.9	25.6	16.6

N, nitrogen; P, phosphorus; K, potassium; Mg, magnesium; Ca, calcium; Fe, iron; Mn, manganese; Cu, copper; Zn, zinc; LSD, least significant difference; CV, coefficient variation. Columns sharing the same letter are not significantly different at $P < 0$.

3.2. Chlorophyll content and photosynthetic rate

The chlorophyll content of tomato plants was significantly ($P < 0.05$) different among the nutrient solutions (Table 2). However, the performance of nutrient solutions varied according to the growth stage of the plants. Tomato plants grown in wastewater treatments (ABR effluents and ABR + CHFM) were slightly greener compared to plants grown in the control treatment (CHFM). Based on the growth stage of the plants, the chlorophyll index of young leaves was higher in the fertilizer supplemented wastewater than the plants fed ABR effluents and CHFM at the seedling stage. However, there was a gradual decline of chlorophyll content at the vegetative and harvest stage. ABR effluents and CHFM obtained the highest chlorophyll content at the vegetative and harvesting stage compared to plants grown in ABR + CHFM. Unlike the ABR + CHFM fed plants, the chlorophyll content of plants grown in ABR and CHFM increased with an increase in plant growth and reached a peak at the harvesting stage. The decline in chlorophyll content of ABR + CHFM fed plants in relation to the growth stage can be attributed to the increase in nutrient demand by the leaves for the synthesis of chlorophyll, which is triggered by a faster growth rate. As the plant grows, translocation of nitrogen from leaves to the reproductive organs takes place due to senescence, hence the reduction in leaf chlorophyll content (Jeuffroy et al., 2002). On the other hand, high chlorophyll content of plants grown in ABR and ABR + CHFM effluents for all the respective growth stages could be partly due to a high level of micronutrients such as zinc, iron, manganese and copper observed in this study. Increased levels of zinc and iron in plant leaves have been reported to increase chlorophyll content in plant because, the nutrients act as a structural component of proteins and enzymes which are responsible for normal development of pigments biosynthesis (Hisamitsu et al., 2001).

Furthermore, the absorption of NH_4^+–N at levels not toxic to tomato plants could also be associated with high accumulation of chlorophyll content for the wastewater fed plants. NH_4^+–N is the dominant N-form and the main end product of the domestic wastewater using an anaerobic baffled reactor system (Musazura et al., 2015). The high concentration of NH_4^+–N in the ABR reactor primarily comes from ammonification caused by a high concentration of BOD_5 due to anaerobic conditions (Singh et al., 2009). There were no significant ($P < 0.05$) differences in the photosynthetic rate (A) of young leaves of plant among the treatments. These results suggest that supplementing wastewater with chemical fertilizers had no effect on the physiological performance of plants. Similar findings were reported by Roosta et al. (2011), in which the supplement of fish waste effluents with chemical fertilizer had no effect on chlorophyll fluorescence of tomato plants grown in aquaponics.

3.3. Biomass production and fruit yield indicators

The results in Figure 2 showed that tomato plants grown in anaerobic baffled reactor treated wastewater effluents had poor performance in terms of shoot fresh weight, shoot dry weight and total biomass compared to the ABR + CHFM and CHFM treatments. However, plants grown in ABR + CHFM had similar performance with those fed with CHFM treatment. The marginal differences between the two treatments, despite considerable variations in nutrient concentration for the different nutrient solutions, was unexpected. As above mentioned, ABR effluents had a higher concentration of micronutrients while CHFM had higher levels of macronutrients. A similar trend of higher fruit yield indicators was noted as was for plant fresh and dry biomass being the lowest in plants fed with ABR wastewater and significantly higher in plants grown in wastewater supplemented with chemical fertilizer and plants grown in commercial hydroponic fertilizer mix. Tomato plants fed with fertilizer supplemented wastewater obtained comparable results with the plants grown in CHFM on yield and fruit number, except for fruit mass per plant. The fruit mass of plants grown in ABR effluent treatment was significantly different from the CHFM treatment. This may be associated with the fact that ABR grown plants produced few fruits per tree compared to the CHFM treatment which eliminated competition of resources among fruits. The higher yield production of tomato plants in the supplemented wastewater may be associated with its enrichment with macro and micronutrients essentially for plant growth.

3.4. Shoot nutrients concentration

There were significant differences between the three nutrient solutions with respect to shoot nutrient uptake (Table 3). Plants grown in ABR wastewater obtained significant lower concentration of nutrients essential for tomato production (N, P, K and Ca) except for Mg which was significantly higher than the fertilizer supplemented wastewater and commercial hydroponic fertilizer mix. However, the micronutrients (Mn, Cu and Fe) were high in the shoots of plants fed with ABR wastewater, except for Zn which was significantly lower than the ABR + CHFM and CHFM. Supplementing wastewater with a half dose of CHFM increased the level of both macro and micronutrients, except for phosphorus which remains lower in the two wastewater nutrient solutions. The low level of shoot phosphorus in the treatments may be associated with a high level of pH in the nutrient solutions. From the day of transplant to the harvesting period, the nutrient solution pH for ABR + CHFM effluents and CHFM treatment ranged from 7.49-8.02 and 6.69–7.71, respectively.

The results are in contrast with the findings of Dyśko et al. (2009), who reported a 13 % reduction in yield as well as tissue P content of tomato plants when the nutrient solution pH was increased from 5.5 to 6.5. The pH of the nutrient solution is one of the important factors that need to be optimized in a hydroponic system due to its role in nutrients stability and availability (Mekuto et al., 2016). The concentration of Cu was also significantly affected by the different nutrient solutions treatments. High values were recorded in tomato shoots grown in ABR wastewater. It was also observed that tomato plants grown in fertilizer supplemented wastewater accumulated less Cu than ABR wastewater treatment. This may be caused by a dilution effect as plants grown in ABR + CHFM treatment produced high biomass than ABR wastewater treatment.

A similar trend was observed with shoot magnesium and iron content. The shoot iron content was beyond the permissible limits of 150 mg/kg (Khan et al., 2011) for all the treatments including the commercial hydroponic fertilizer mix. The highest Fe shoot content was recorded in tomato plants grown in fertilizer supplemented wastewater followed by ABR wastewater effluents and lastly, CHFM treatment. These results indicated that in terms of macro and micronutrient composition, ABR wastewater effluents contain a high concentration of micro (Mn, Cu and Fe) nutrients and a lower concentration of macronutrients (N, P, K and Ca) compared to commercial hydroponic fertilizer which recorded opposite results. The variation among the treatments in terms of shoot nutrients explains the variation in plant growth and yield performance of plants. The non-significant response between fertilizer supplemented wastewater and commercial hydroponic fertilizer mix could be caused by the trade-offs in nutrients between wastewater and CHFM.

3.5. Conclusion

The findings from this research indicate that effluents generated from the secondary treated wastewater (ABR), a component of decentralised wastewater treatment system, showed the potential to be used as a source of fertilizer for tomatoes grown in hydroponic system. The capacity of wastewater to support plant growth in hydroponic system is due to its multi-nutrient characteristic, which improved the chlorophyll content and photosynthetic rate of tomato plants. This could be associated with the high levels of micronutrients content such as Cu, Zn, Fe and Mg. However, results observed from this study also indicated that fertigation of tomato plants with ABR effluents in a hydroponic system is not sufficient to support plant growth. The low concentration of essential nutrients such as N, P, K, Ca & Zn in wastewater is the reason for reduced growth and yield performance as compared to plants fed with commercial fertilizer mix. However, plants grown from commercial hydroponic fertilizer mix added to ABR effluent showed increased plant growth, yield performances and shoot nutrients content. This indicated that the addition of a 50 % dose of commercial hydroponic fertilizer to the wastewater in ABR effluent increased nutrient availability to plants. However, the nutrient solutions were changed on a weekly basis which might result in nutrient losses in the hydroponic system. Further research should focus on operational parameters such as nutrient retention time, aeration, pH and EC adjustment in the hydroponic system. This will increase nutrient uptake by plants through enhanced nutrient availability, improve the activity of microorganisms which may further facilitate the removal or degradation of organic nitrogen thereby increasing their availability to plants. Moreover, the basis for determining the accurate amount of chemical fertilizer to be added to the wastewater still needs to be established.

Declarations

Author contribution statement

Shirly Tentile Magwaza: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Lembe Samukelo Magwaza: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Alfred Oduor Odindo, Asanda Mditshwa, Christopher Buckley: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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