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Research article

Biogas digestates are not an effective nutrient solution for hydroponic tomato (*Lycopersicon esculentum* L.) production under a deep water culture system

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ABSTRACT

The generation of energy through anaerobic digestion using animal manures is being promoted as an environmentally sustainable method of managing animal wastes. However, sustainability of biogas production is reliant on the sustainable utilization of the digestates that emanate from the process. Our study evaluated the effects of the biogas digestates on crop phytotoxicity and their fertilizer potential as a nutrient solution in hydroponic tomato production. Biogas digestates diluted up to 40% (v/v) resulted in significantly ($P < 0.05$) the lowest relative seed germination (RSG) in all vegetables evaluated in our study. The highest RSG was observed in the 10% biogas digestates, which was higher than the control treatment. For the crop growth study, relative to the control,the treatments with 20%, 40% and 60% mineral fertilizer substitution resulted in 39.4%; 22.8% and 8.7% significantly ($P < 0.05$) lower chlorophyll content, respectively. On average, the treatments with biogas slurry, though substituted with mineral fertilizers, resulted in a 275% lower fresh fruit yield compared to the control treatment. However, with biogas digestates, the sugar content in the tomato fruits significantly increased, whilst the heavy metal content was below that recommended limit when irrigation water is used. The results of our study demonstrated that cow based digestates are not a suitable nutrient media for hydroponic tomato production. Moreover, even with mineral fertilizer supplementation, only the control treatment containing only mineral hydroponic fertilizer resulted in positive growth and yield in tomatoes.

1. Introduction

The fast growth in world population has led to the intensification of activities like food production, energy generation and industrialization. In Sub-Saharan Africa alone, population increase is expected to double, whilst the world population is expected to reach 10 billion by the year 2050 (Smith et al., 2014). To meet this increasing populations' food and energy demands, there has been an increase in intensification of agriculture and industrialization. This intensification has however resulted in overproduction of waste substances such as cow manure, resulting in inappropriate and untimed disposal of the manures especially in agricultural fields (Mupambwa and Mnkeni, 2018). Such disposal carry environmental challenges such as introduction of harmful trace metals, inorganic salts and pathogens into the soil (Lazcano et al., 2008). Technologies that can enhance the sustainable utilization of the large quantities of animal manures being generated throughout the world are currently being promoted. One such technology that is gaining momentum due to its limited environmental footprint is the generation of clean energy using the animal manures in the form of biogas (Lencioni et al., 2016; Insam et al., 2015). The management of animal manures through biogas production is being widely promoted as an important renewable energy source (Sieling et al., 2013). However, the sustainability of biogas production is reliant on suitable utilization of digestate from the biogas production, with their utilization as a fertilizer being the most plausible option (Insam et al., 2015; Coban et al., 2015).

Several researchers have looked at the possibility of making biogas generation a clean energy and zero emissions process by evaluating the fertilizer potential of the effluent from biogas digestion. Studies have reported that the digestate from biogas are high quality nutrient materials rich in macro nutrients such as P, K and in particular, nitrogen (Chen

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et al., 2017; Sheets et al., 2015; Liu et al., 2011; Yu et al., 2010). Due to the abundance of organic matter, nutrients and the presence of bioactive substances, biogas digestates are often applied directly to the soil as an organic fertilizer together with mineral fertilizers (Wang et al., 2019). However, the response of plants fertilized with biogas digestates is variable depending on manure type, with long term soil application presenting a challenge of heavy metal accumulation in soils (Wang et al., 2019). Due to the nutrient composition of biogas digestates, the liquid fraction has been evaluated as a potential fertilizer in soils and hydroponic systems. However the major challenge is their potential phytotoxicity, heavy metal and pathogen addition to the soil and plants (Wang et al., 2019; Lencioni et al., 2016; Sheets et al., 2015; Krishnasamy et al., 2012).

A study by Krishnasamy et al. (2012) evaluated the potential of diluted biogas digestates as a nutrient solution for silver beet under a hydroponic system. It was observed that silverbeet survival was best at 20% digestate whilst at 50%, silverbeet survival was negatively affected due to ammonia toxicity and low oxygen (Krishnasamy et al., 2012). Lencioni et al. (2016) evaluated the phytotoxicity of pig digestate, which had been diluted from 5-30% on different plants, reporting that digestate concentrations that stimulated germination and early seedling growth were as low as 2–3%, whilst 20–30% could be used for the advanced stages with limited negative effects. Tomatoes grown under a bato bucket hydroponics system supplied with nutrients made from a liquid effluent from anaerobic thermophilic digestion of poultry litter grew slowly and produced fewer and smaller tomatoes (Liedl et al., 2004). This was attributed to the sensitivity of tomatoes to ammonia present in the nutrient solution at higher concentrations. However in another study where biogas slurry was used to fertilize tomatoes planted in soil, positive growth and nutrient uptake was reported (Yu et al., 2010).

Though the few studies highlighted above have evaluated the fertilizer value of biogas digestates in hydroponics, there is paucity of information on research that has evaluated their effects on plant growth, nutrient uptake and crop yields. Furthermore, most of these studies have only focused on early seedling growth of leafy vegetables, with none of these studies evaluating their potential on the growth and yield of fruit based vegetables like tomatoes. Our study thus evaluated the phytotoxicity and nutrient potential of biogas digestates produced from cow manure obtained from the Namibian desert area, under a deep water culture hydroponic system for tomato (*Lycopersicon esculentum* L.) production.

2. Materials and methods

2.1. Source of digestate

This study was undertaken at the Sam Nujoma Campus of the University of Namibia, in Henties Bay. The digestate used in this study was collected from a biogas digester located at the Sam Nujoma Campus of the University of Namibia, which had been using cow manure collected from the Uis area located at the edge of the Namib Desert. The digester had been fed once off with fresh cow manure, and the digester room was maintained at a temperature of 30° Celsius throughout the biogas generation process. After exhaustion of the biogas generating process, the liquid fraction of the digestates were collected and stored in plastic containers, until the study was undertaken. Before the start of the study, a sample of the original digestate as well as those from the different treatments including the control were collected, filtered using Whatman No. 2 filter paper, then analyzed for cations and heavy metals using an ICP-OES (model iCAP 6000 Series; Thermo Fisher Scientific). The concentrations of inorganic P and N were analyzed using colorimetric methods outlined by Okalebo et al. (2002). The pH and electrical conductivity was measured potentiometrically in the different solutions corresponding to the different treatments. The selected chemical characteristics of the digestates and control commercial nutrient solution used in this study are shown in Tables 1 and 2.

2.2. Phytotoxicity test

Prior to establishment of the hydroponic study, a phytotoxicity test was undertaken to enable for the identification of the appropriate biogas digestate dilution ratio. In this test, the biogas digestate was diluted on a volume to volume basis, with deionized water to give the following treatments: undiluted biogas digestate; 10%; 20% and 40% biogas digestate, with the control being the normal hydroponic fertilizer. Based on the five treatments, the phytotoxicity test was undertaken using the seed germination and plant growth bioassays as described by Tiquia and Tam (1998) and Ravindran and Mnkeni (2016). Briefly, the filtered sub-samples from the different treatment combinations were used to saturate two Whatman filter papers, which were then placed inside a sterile petri dish. Ten seeds of tomato (*Lycopersicon esculentum*), spinach (*Spinacia oleracea*), carrot (*Daucus carota*), beetroot (*Beta vulgaris*) and cabbage (*Brassica oleracea* var. *capitata*) were placed on top of the filter papers and incubated for 3 days in dark conditions at 25° Celsius. After the 3 day incubation, the seed germination, relative seed germination (RSG) calculated based on Eq. (1), relative root elongation (RRE) calculated based on Eq. (2) and germination index (GI) calculated based on Eq. (3).

$$\text{RSG} \ (\%) = \frac{\text{Number of seeds germinated in the sample extract}}{\text{Number of seeds germinated in control extract}} \times 100 \quad (1)$$

$$\text{RRE} \ (\%) = \frac{\text{Mean root elongation in the sample}}{\text{Mean root elongation in control extract}} \times 100 \quad (2)$$

Table 1
pH and Electrical conductivity (EC) of hydroponic fertilizer and cow manure based biogas digestate diluted with water.

	Undiluted biogas digestate	10% Biogas slurry	20% Biogas slurry	40% Biogas slurry	Control (normal hydroponic fertilizer)
pH	8.04 ± 0.06	7.84 ± 0.27	7.78 ± 0.16	7.90 ± 0.07	7.69 ± 0.02
EC (μS/cm)	1003.1 ± 6.2	214.5 ± 13.1	290.3 ± 2.1	425.7 ± 2.1	275.7 ± 13.2

Values expressed as mean ± standard deviation (n = 3).

Table 2
Yield parameters of tomatoes grown in biogas digestate substituted with different levels of mineral based hydroponic fertilizer.

Treatment	Chlorophyll content Index	Fresh yield (g/plant)	Sugar content (Brix values)	Number of fruits	Number of flowers
Control (hydroponic fertilizer)	28.16a	150.53a	5.03c	14.3a	29.0a
20%	20.20c	9.76d	9.07a	1.7d	5.0c
40%	22.93bc	26.67c	7.37b	4.0c	13.7b
60%	25.90ab	84.00b	6.57b	6.7b	15.0b

Values within the same column followed by a different letter are significantly different at $P < 0.05$.

Table 3
Phytotoxic effects of cow manure based biogas digestate diluted at different levels with water on selected vegetables.

Treatments	Cabbage	Spinach	Carrot	Tomato	Beetroot
Relative Seed Germination (%)					
Control	95.0a	103.7	95.0c	86.2a	19.2c
10% Biogas slurry	96.7a	96.3	130.0a	79.3a	46.2b
20% Biogas slurry	93.3a	96.3	110.0b	58.6b	69.2a
40% Biogas slurry	70.0b	103.7	0d	48.3c	26.9bc
***P* value**	0.0104	ns	<0.0001	0.0003	0.0053
Relative Root Elongation (%)					
Control	45.7b	93.9c	63.6a	120.2a	67.2a
10% Biogas slurry	86.1a	154.1a	109.1a	145.6a	87.4a
20% Biogas slurry	83.1a	134.4ab	116.6a	81.1b	81.8a
40% Biogas slurry	31.5c	104.6bc	0.0b	42.9c	21.5b
***P* value**	0.0002	0.0166	0.0063	0.0016	0.0081
Germination Index (%)					
Control	43.6b	96.9	60.5b	104.1a	13.7b
10% Biogas slurry	83.1a	149.2	143.3a	115.3a	41.5a
20% Biogas slurry	77.6a	130.0	126.1a	47.7b	55.1a
40% Biogas slurry	22.6c	108.5	0c	20.7b	6.2b
***P* value**	0.0002	ns	0.0055	0.004	0.0041

Values within the same column followed by a different letter are significantly different at $P < 0.05$.
ns = not significant at $P > 0.05$.

$$GI\ (\%) = \frac{(\%\ \text{Seed germination}) \times (\%\ \text{root elongation})}{100} \quad (3)$$

2.3. Tomato crop growth

Based on results of the phytotoxicity study and the elemental composition, the most appropriate dilution level for the biogas digestate of 10% was selected for use in the tomato crop growth study. Due to the low nutrient content in the biogas digestate, the treatments in this study were thus based on the various levels of commercial hydroponic fertilizer substitution into the 10% diluted solution. This gave the following treatments: 100% normal hydroponic fertilizer (control); 20%; 40% and 60% added as normal hydroponic fertilizer to supplement the 10% biogas digestate solution. These substitution levels were designed to allow the study to identify which level of the commercial fertilizer supplementation can give the highest crop growth whilst reducing the quantity of the expensive commercial fertilizer used. The treatments based on the level of commercial fertilizer supplementation were replicated 3 times and laid in a completely randomized design.

Rectangular plastic containers with a 30 L capacity were used for the deep water culture hydroponic system, with a floating styrofoam, onto where the hydroponic planting cups with the seedlings were placed. In each hydroponic planting tray, 2 tomato plants (variety Roma Ven), were planted and these were monitored for pests and diseases until maturity. At maturity, the number of fruits, number of flowers, chlorophyll content, fruit fresh weight and fruit sugar content were measured. To determine the plant nutrient uptake, the tomato above ground biomass was harvested, dried at 60 ° Celsius and grinded with a plant grinder. The grinded plant samples from the respective treatments were then digested using a mixture of Nitric acid and Perchloric acid on a block digester as outlined by AgiLASA (2004). The digested samples were then analyzed for total concentrations of Ca, K, Mg, Na, Pb, Zn, Cr and Cd using ICP-OES model iCAP 6000 Series; Thermo Fisher Scientific.

2.4. Statistical analysis

The data collected was subjected to analysis of variance (ANOVA) using JMP version 12.0.1 statistical package (SAS Institute, Inc., Cary, NC, USA) whilst Microsoft Excel 2013 was used for the construction of graphs. Means were further separated using Fishers Protected Least Significant Difference where ANOVA indicated a significant *P* value ($P < 0.05$).

3. Results

3.1. Effects of biogas digestates on vegetable crop phytotoxicity

The phytotoxicity of the various biogas dilutions were determined using seeds of five popular vegetables. Significant differences ($P < 0.05$) were observed on relative seed germination (RSG) for all vegetables except for spinach (Table 3). The highest concentration of the biogas slurry i.e. the 40% treatment, resulted in significantly the lowest RSG in all vegetables except for spinach. At this highest concentration, the germination of carrot was completely suppressed resulting in a RSG of 0%. For most of the vegetables, the treatments with 10% biogas slurry resulted in the highest RSG which was higher than the control treatment of hydroponic fertilizer alone.

The relative root elongation (RRE), which express the root growth relative to the control was generally highest in treatments where biogas slurry was added compared to the control (Table 3). Across all treatments and vegetables, significant differences ($P < 0.05$) were observed on RRE. Generally, the RRE followed the order 10% biogas slurry >20% biogas slurry > control >40% biogas slurry. Across all the five crops, the 10% biogas slurry treatment showed an average of 116.5% RRE, which was 46.5% more than the control and 190.4% more than the 40% biogas slurry treatment. For all the crops except for beetroot, the 10% biogas slurry treatment resulted in the highest germination index ($P < 0.05$; Table 3). Similar to other parameters, the 40% biogas slurry treatment showed the lowest germination index (GI) for all crops except in spinach. The 10% biogas slurry treatment actually resulted in a 67.2% higher GI relative to the normal hydroponic fertilizer.

3.2. Influence of fertilizer substitution on nutritional composition of biogas slurry

The control treatment with the 100% hydroponic fertilizer had significantly ($P < 0.05$) the highest concentrations of phosphorus and nitrogen (Table 4). The subsequent substitution of the biogas slurry with the hydroponic fertilizer from 20% to 60% resulted in a direct increase in the concentration of P and N. Relative to the control treatment, the 20% substituted treatment showed a 5.6 and 4.8 times less P and N, respectively. Unlike for P and N, the concentrations of the cations Na, Ca, Mg and K were significantly higher ($P < 0.05$) in the treatments with biogas slurry, with the control having the lowest concentrations. The concentration of Ca and K in the 20% substituted treatment was 107.7% and

Table 4
Nutritional and chemical composition of biogas digestate supplemented with mineral based hydroponic fertilizer.

Treatment	P mg/L	N (NO_2; NO_3; NH_4)	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Pb mg/L	Zn mg/L	pH mg/L	EC µS/cm
Control (hydroponic fertilizer)	124.7a	333.3a	143.7c	197.1bc	44.3c	115.1 b	0.0b	0.15a	7.69a	275.7b
20%	22.3d	69.2d	298.4a	224.5a	102.4b	152.2a	0.0012a	0.08a	7.87a	322.8a
40%	32.6cd	102.4c	161.2bc	208.2b	121.9a	167.4a	0.0010a	0.10a	7.84a	344.2a
60%	41.1b	184.2b	172.8bc	192.4bc	135.2a	160.8a	0.0015a	0.08a	7.91a	356.7a

Values within the same column followed by a different letter are significantly different at $P < 0.05$.

13.9% more relative to the control treatment. However, for Mg the highest concentration was observed in the 60% substituted treatment, whilst for Na, the highest concentration was observed in the 40% substituted treatment.

Several trace metals which include As, Cd, Cr, Ni, Zn and Pb were measured in this study. However, it was noteworthy that the concentrations of most of these metals were below detectable limits (data not shown) except for Pb and Zn only (Table 4). Of these two metals, there were no significant differences observed between the treatments on concentrations of Zn, whilst significant differences ($P < 0.05$) were observed for Pb. The concentration of Pb ranged from 0 to 0.0015 mg/L whilst that of Zn ranged from 0.08 to 0.15 mg/L.

The pH in the different treatments was not significantly different, with all values being neutral ranging from 7.69 to 7.91. However, pH was slightly higher in the treatments with biogas slurry, resulting in an average 2.4% difference relative to the control. The electrical conductivity (EC) was also significantly higher in the treatments with biogas slurry whilst it was lowest in the control treatment. On average, EC within the treatments with biogas slurry was 23.8% higher compared to the EC in the control treatment. Across all the treatments, EC ranged from 275.7 to 356.7 μS/cm.

3.3. *Influence of fertilizer substitution into biogas slurry on tomato yield parameters*

The chlorophyll content of a plant is a general indicator of nutrient status and nutrient response of the plant. In our study, chlorophyll content was expressed as an index ranging from 1 to 45, with 1 being the lowest. There were significant differences observed between treatments on chlorophyll content index (CCI), with the control having the highest values whilst the 20% substituted treatment had the lowest index (Table 4). Relative to the control treatment, the 20%, 40% and 60% substituted treatments resulted in 39.4%; 22.8% and 8.7% significantly ($P < 0.05$) lower CCI. The marketable fresh fruit yield was significantly different ($P < 0.05$) among all treatments, with a clear trend where the higher the fertilizer substitution, the higher the tomato yield. Relative to the control, the 20%; 40% and 60% treatments resulted in 14.4; 4.6 and 0.8 times less fresh fruit yield, respectively.

It was important to note that substitution of the biogas slurry even with 60% of the hydroponic fertilizer did not result in fruit yields comparable to those in the control treatment. On another note, the sugar content which was measured in Brix units, increased with a decrease in nutrient substitution of the different treatments (Table 5).

There were statistically significant ($P < 0.05$) differences in sugar content with the 20% substituted treatment having the highest sugar content whilst the control had the lowest content. Relative to the control treatment, the 20%, 40% and 60% resulted in 80.3%; 46.5% and 30.6% more sugar content, respectively. The last parameters measured to determine yield were the number of fruits and flowers between the treatments. Similar to fresh yield results, there were significant differences ($P < 0.05$) observed among treatments, with the control having the highest number of fruits and flowers, whilst the 20% substituted treatment had the lowest numbers (Table 4). Compared to the control treatment, the 20%; 40% and 60% treatments resulted in 7.4; 2.6 and 1.1 times less number of fruits, respectively. In a similar trend, relative to the control, the 20%; 40% and 60% treatments resulted in 4.8; 1.1 and 0.9 times less number of flowers, respectively (Table 4).

3.4. *Influence of fertilizer substitution into biogas slurry on plant elemental uptake*

For the cations Ca, Mg, K and Na in the tomato plant biomass, the 20%

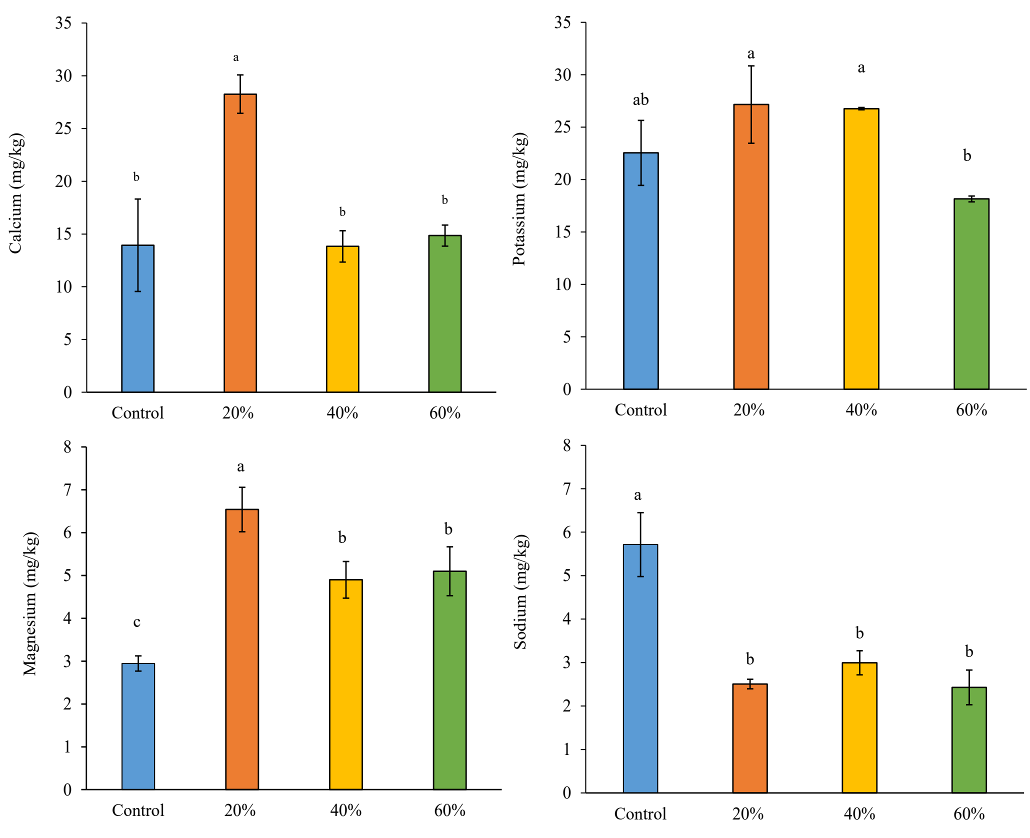

Fig. 1. Nutrient (Ca, K, Mg and Na) absorption by tomato plant biomass under a biogas slurry substituted with different levels of hydroponic fertilizer. Error bar represent standard deviation.

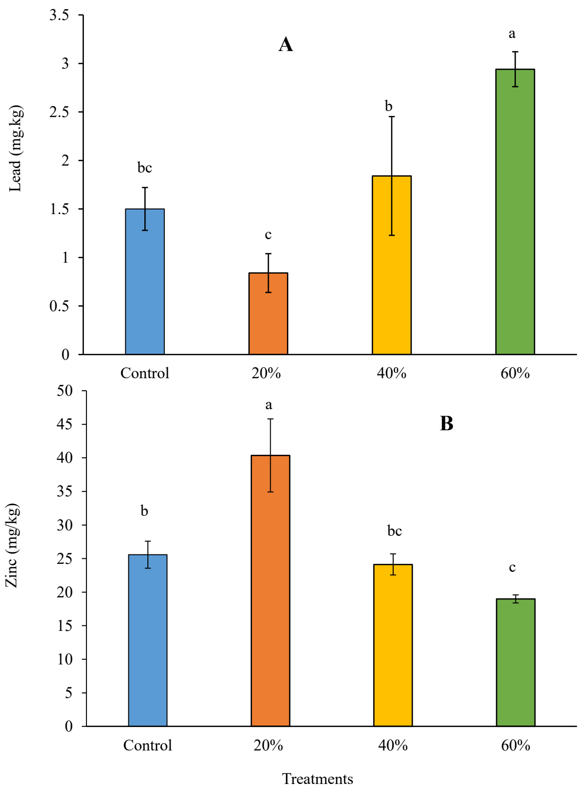

Fig. 2. Influence of different levels of hydroponic fertilizer substitution into biogas digestate on tomato biomass Pb (A) and Zn (B) uptake. Error bars indicate standard deviation.

substituted treatment resulted in significantly ($P < 0.05$) the highest uptake of Ca and Mg (Fig. 1). For Ca uptake, the 20% substituted treatment resulted in 102.7% more Ca, whilst the 40% and 60% substituted treatments resulted in an average 2.9% more Ca only, relative to the control. For K concentration, as the concentration of the hydroponic fertilizer substitution increased, the uptake of K by the plant decreased. The K in the tomato plant biomass under the 20% substituted treatment was 20.4% more than that of the control treatment. The lowest concentration of Mg in the plant biomass was observed in the control treatment, which was 122% less than that observed in the 20% substituted treatment. However, there were no significant differences observed between the 40% and 60% substituted treatments for Mg concentration. It was interesting to note that Na concentration was significantly ($P < 0.05$) the highest in the control treatment, whilst the biogas digestate based treatments did not record significantly different concentrations (Fig. 1). On average, the Na concentration in the control treatment was 116.3% more relative to all the three biogas digestate based treatments.

The concentration of most of the measured trace metals in the tomato plant biomass was below detectable limits except for Pb and Zn only (Fig. 2). The concentration of Pb in the plant biomass showed an unusual trend across the treatments, with the 60% substituted treatment having the highest concentration whilst the 20% substituted treatment had the lowest concentration. The concentration of Pb in the 40% and 60% substituted treatments was 22.7% and 96% higher, respectively, compared to the control treatment, whilst the 20% substituted treatment recorded a 78.6% less Pb, compared to the control. On the contrary, the concentration of Zn in the plant biomass significantly ($P < 0.05$) decreased with an increase in the level of substitution of the hydroponic fertilizer (Fig. 2). The 60% substituted treatment recorded plants with the lowest concentration of Zn followed by the control. The concentration of Zn in plants within the 20% substituted treatment was 57.8% higher, relative to the control.

4. Discussion

Biogas digestates have been reported to have high levels of biological oxygen demand, suspended solids and low dissolved oxygen, whilst being rich in nutrients such as N and P (Krishnasamy et al., 2012). However, studies that have evaluated the fertilizer potential of these digestates in hydroponics crop production are scarce (Wang et al., 2019; Sheets et al., 2015; Sieling et al., 2013). In our study, the raw biogas digestate diluted at 20% and 40% resulted in crop phytotoxicity as indicated by the low germination indices. Germination index (GI) is a very sensitive parameter used for evaluating the phytotoxicity of organic materials and GI indices below 50% have been reported to indicate materials unsuitable for use in crop production (Ravindran and Mnkeni, 2016; Raj and Antil, 2011; Bernal et al., 2009). These lower GI have been attributed to heavy metals, ammonia and low molecular weight compounds that reduce seed germination and root elongation (Raj and Antil, 2011). Though heavy metals were significantly low in the raw biogas digestates (Table 2), it is possible that the presence of higher levels of ammonia versus nitrates and other organic compounds in the digestates used in our study could have resulted in elevated phytotoxicity at higher concentrations of biogas digestates (Moller and Muller, 2012; Liedl et al., 2004). Moreover, the observed phytotoxicity cannot be explained by the electrical conductivity or medium salt content, as these were well within the recommended values. It was also noted that different crops showed varying phytotoxicity responses to the biogas digestates, indicating the difference in their tolerance levels.

Several researchers have indicated that biogas digestates are very high in phosphorus and nitrogen, as these are not utilized during the anaerobic digestion process (Coban et al., 2015; Sieling et al., 2013). However, the concentration of these nutrients is highly dependent on the source of the manure. In our study, the manure was collected from animals that had been feeding on natural shrubs from the Namib Desert, whose macro nutrient content is very low. This could explain the low macro nutrient (N and P) contents observed in the biogas slurry, which were not in the same range as reported by Juan et al. (2018). The low macro nutrient concentrations therefore informed the need for substitution of the biogas slurry with the different levels of inorganic hydroponic fertilizer. Even under substitution with hydroponic fertilizer, the macro nutrient levels in the biogas digestate based treatments remained low in our study. This clearly indicates the lack of positive benefit from the cow manure based biogas digestate especially on the concentrations of macro nutrients in hydroponic nutrient solutions. However, the concentration of the cations was increased under the biogas based treatments, which is in agreement with results of Wang et al. (2019) even when only 2.6% biogas digestate were used with mineral fertilizers. The results of our study therefore indicate that the diluted biogas digestate can be an important source of micro nutrients such as Ca and Mg, though supplementation with other sources of macro nutrients is required. It was interesting to note that the concentration of heavy metals in the biogas digestate were lower than the recommended limit for irrigation water (Wang et al., 2019). These higher concentrations of elements like Ca and Mg as well as the lower concentration of heavy metals observed in the tomato plant biomass can be explained by the nutritional composition of the nutrient solutions used in this study.

The yield parameters which include chlorophyll content, fresh yield and number of fruits all showed a direct response to the concentration of N and P in the different solutions. These reductions in yield properties of the tomatoes could be attributed to the variability and imbalance in nutrient composition of biogas digestate based hydroponic solutions (Moller and Muller, 2012). According to Moller and Muller (2012), in crops like tomatoes, conversion of ammonia to nitrates and nitrites together with supplementation of micro-nutrients may be required before biogas digestates are used in hydroponic culture. Based on the results of our study, the high nutrient demand for tomatoes suggest that other less demanding crops such as lettuce may be more suitable for cultivation using cow based biogas digestates. However, the sugar concentration was inversely related to the nutritional composition of the hydroponic growth media in our study. Similar results were reported by Wang et al. (2019) and this has been attributed to plant physiological response to high salt content under the biogas digestate based treatments.

5. Conclusion

The study evaluated the potential fertilizer value of cow based biogas digestate as a nutrient source for hydroponic tomato production under a deep water culture system. The results of our study demonstrated that cow based digestates are not a suitable nutrient media for hydroponic tomato production. Moreover, even with mineral fertilizer supplementation, the biogas digestate based treatments failed to outperform the control treatment, which resulted in positive growth and yield in tomatoes. The low macro-nutrient concentrations of the cow based biogas digestates could make them suitable for use only in less nutrient demanding crops like lettuce. Due to possible ammonia phytotoxicity, there is a need to evaluate methods of converting the higher levels of ammonia in digestates before their utilization as a hydroponic fertilizer. There may be a need of evaluating biogas digestates produced from protein rich animal manures like chicken and pigs in production of different crops whilst periodic analysis to monitor changes in nutrient content during such crop growth studies is also recommended.

Declarations

Author contribution statement

H. A. Mupambwa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

A. S. Namwoonde, G. M. Liswaniso: Performed the experiments; Contributed reagents, materials, analysis tools or data.

M. K. Hausiku: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

B. Ravindran: Conceived and designed the experiments; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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References

Agri Laboratory Association of Southern Africa (AgriLASA), 2004. Soil Handbook. Pretoria (South Africa): Agri Laboratory Association of Southern Africa. Pretoria, South Africa.

Bernal, M.P., Alburquerque, J.A., Moral, R., 2009. Composting of animal manures and chemical criteria for compost maturity assessment. A review. Bioresour. Technol. 100, 5444–5453.

Chen, G., Zhao, G., Zhang, H., Shen, Y., Fei, H., Cheng, W., 2017. Biogas slurry use as N fertilizer for two-season Zizania aquatica Turcz. in China. Nutrient Cycl. Agroecosyst. 107, 303–320.

Coban, H., Miltner, A., Elling, F.J., Hinrichs, K.U., Kastner, M., 2015. The contribution of biogas residues to soil organic matter formation and CO_2 emissions in an arable soil. Soil Biol. Biochem. 86, 108–115.

Insam, H., Gomez-Brandon, M., Ascher, J., 2015. Manure-based biogas fermentation residues - friend or foe of soil fertility? Soil Biol. Biochem. 84, 1–14.

Juan, J., Muhammad, K., Zhao, H., Yang, L., Muhammad, B., Gao, Z., Tang, D., Huang, D., 2018. Impact of biogas slurry fertilizer on growth, quality and biochemical characteristics of ornamental lettuce '*Biscia rossa*'. Pak. J. Bot. 50 (1), 123–129.

Krishnasamy, K., Nair, J., Bauml, B., 2012. Hydroponic system for the treatment of anaerobic liquid. Water Sci. Technol. 65, 1164–1171.

Lazcano, C., Gomez-Brandon, M., Dominguez, J., 2008. Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. Chemosphere 72, 1013–1019.

Lencioni, G., Imperiale, D., Cavirani, N., Marmiroli, N., Marmiroli, M., 2016. Environmental application and phytotoxicity of anaerobic digestate from pig farming by in vitro and in vivo trials. Int. J. Environ. Sci. Technol. 13, 2549–2560.

Liedl, B., Cummins, M., Young, A., Williams, M.L., Chatfield, J.M., 2004. Liquid effluent from poultry waste bioremediation as a potential nutrient source for hydroponic tomato production. Acta Hortic. (Wagening.) 659, 647–652.

Liu, W.K., Yang, Q.C., Du, L.F., Cheng, R.F., Zhou, W.L., 2011. Nutrient supplementation increased growth and nitrate concentration of lettuce cultivated hydroponically with biogas slurry. Acta Agric. Scand. Sect. B Soil Plant Sci 61, 391–394.

Moller, K., Muller, T., 2012. Effects of anaerobic digestion on digestate nutrient availability and crop growth: a review. Eng. Life Sci. 12, 242–257.

Mupambwa, H.A., Mnkeni, P.N.S., 2018. Optimizing the vermicomposting of organic waste materials for production of nutrient rich organic fertilizers: a review. Environ. Sci. Pollut. Control Ser. 25, 10577–10595.

Okalebo, J.R., Gathua, K.W., Woomer, P.L., 2002. Laboratory Methods of Soil and Plant Analysis: A Working Manual. TSBF-KARI-UNESCO, Nairobi, Kenya.

Raj, D., Antil, R.S., 2011. Evaluation of maturity and stability parameters of composts prepared from agro-industrial wastes. Bioresour. Technol. 102, 2868–2873.

Ravindran, B., Mnkeni, P.N.S., 2016. Bio-optimization of the carbon-to-nitrogen ratio for efficient vermicomposting of chicken manure and waste paper using *Eisenia fetida*. Environ. Sci. Pollut. Control Ser. 23, 16965–16976.

Sheets, J.P., Yang, L., Ge, X., Wang, Z., Li, Y., 2015. Beyond land application: emerging technologies for the treatment and reuse of anaerobically digested agricultural and food waste. Waste Manag. 44, 94–115.

Sieling, K., Herrmann, A., Wienforth, B., Taube, F., Ohl, S., Hartung, E., Kage, H., 2013. Biogas cropping systems: short term response of yield performance and N use efficiency to biogas residue application. Eur. J. Agron. 47, 44–54.

Smith, J., Abegaz, A., Matthews, R.B., Subedi, M., Orskov, E.R., Tumwesige, V., Smith, P., 2014. What is the potential for biogas digesters to improve soil fertility and crop production in Sub-Saharan Africa? Biomass Bioenergy 70, 58–72.

Tiquia, S.M., Tam, N.F.Y., 1998. Elimination of phytotoxicity during co-composting of spent pig manure sawdust litter and pig sludge. Bioresour. Technol. 65, 43–49.

Wang, L., Guo, S., Wang, Y., Yi1, D., Wang, J., 2019. Poultry biogas slurry can partially substitute for mineral fertilizers in hydroponic lettuce production. Environ. Sci. Pollut. Control Ser. 26, 659–671.

Yu, F., Luo, X., Song, C., Zhang, M., Shan, S., 2010. Concentrated biogas slurry enhanced soil fertility and tomato quality. Acta Agric. Scand. Sect. B Soil Plant Sci 60, 262–268.