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Hydroponic system for the treatment of anaerobic liquid

K. Krishnasamy, J. Nair and B. Bäuml

ABSTRACT

The effluent from anaerobic digestion process has high concentrations of nutrients, particularly nitrogen essential for plant growth but is not suitable for direct disposal or application due to high chemical oxygen demand (COD), low dissolved oxygen (DO), odour issues and potentially phytotoxic. This research explored the optimum conditions of anaerobic effluent for application and dilutions of the effluent required to obtain better plant growth. A small-scale hydroponic system was constructed in glasshouse to test different concentrations of anaerobic effluent against a commercial hydroponic medium as the control for the growth of silverbeet. It was found that the survival of silverbeet was negatively affected at 50% concentration due to low DO and NH_4-toxicity. The concentration of 20% anaerobic liquid was found to be the most efficient with highest foliage yield and plant growth. The hydroponic system with 20% concentrated effluent had better utilisation of nutrients for plant growth and a COD reduction of 95% was achieved during the 50 days growth period. This preliminary evaluation revealed that the growth and development of silverbeet was significantly lower in anaerobic effluent compared to a commercial hydroponic plant growth solution. The nutrient quality of anaerobic effluent could be highly variable with the process and the waste material used and dilution may depend on the nutrient content of the effluent. It is recommended that, a pre-treatment of the effluent to increase DO and reduce ammonium content is required before plant application and simple dilution by itself is not suitable for optimum plant growth in a hydroponic system.

Key words | anaerobic digestion, anaerobic effluent, hydroponics, silverbeet, wastewater treatment

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INTRODUCTION

Anaerobic digestion is a widely used process to treat organic wastes while producing biogas and is considered to be an alternative way to reduce dependence on fossil fuel energy (Langley 1979). Liquid effluent from anaerobic digestion after microbial reactions has high levels of BOD (biological oxygen demand), COD (chemical oxygen demand), SS (suspended solids); low in DO (dissolved oxygen) and rich in nutrients (Salminen *et al.* 2001; Dosta *et al.* 2007).

Anaerobic effluent is a nutrient rich fertiliser since most of the original nutrients present in the feed stock are present in the residue and may contribute to plant nutrition or enhance soil fertility (Salminen *et al.* 2001). However, the use of untreated anaerobic effluent may pose several human health problems, odour and environmental pollution. During anaerobic digestion, a major proportion of organic nitrogen is converted into ammonium (Salminen *et al.* 2001; Liedl *et al.* 2006) which is phytotoxic, if present at high concentrations (Tiquia *et al.* 1996). The pH of the effluent is critical as under pH greater than 7.5, ammonium converts to NH_3 which exists as a dissolved gas (Demuynk *et al.* 1979). Dissolved ammonia is more toxic to plants than ammonium ion (Hageman 1984). There are elevated levels of BOD, COD, and nutrients in the effluent (Dosta *et al.* 2007) that have the potential to pollute the environment if disposed without treatment.

On the other hand, the use of wastewater for cultivation is a sustainable option and is becoming a necessity due to the limitations in availability of freshwater for irrigation

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(Nair *et al.* 2008). It has been proposed that integration of hydroponic cultivation into effluent treatment process is an ecological alternative to remove nutrients from the wastewater through plant uptake (Norstrom 2005). Therefore there is a potential to combine anaerobic digestion process for waste treatment and hydroponic systems for a dual advantage of pollution reduction and crop production. Although the anaerobic effluent contains plant nutrients in various chemical forms, there is a lack of detailed scientific research in the potential use of effluent as a liquid fertiliser.

The main aim of this study is to look at the possibility of treating anaerobic effluent using hydroponic system and also to consider the possibility of recycling the nutrients for crop production, and to investigate the percentage of effluent dilution required to produce better yield. A pilot scale experiment was conducted under controlled environmental conditions to study the growth of silver beet in anaerobic effluent generated from food waste digestion in anaerobic effluent and also to compare it with a commercial nutrient solution used as control.

Table 1 | Characteristics of the undiluted anaerobic effluent and the commercial hydroponic solution

Parameters (mg/L*)	Anaerobic effluent ($n = 3$)	Control
pH	7.72 ± 0.01	5.8
EC (dS/m)	7.32 ± 0.15	2.5
DO	0.27 ± 0.12	–
COD	1,258 ± 37	–
Total N	683 ± 1.9	1,930
NH_4	475 ± 5.3	23,150
NO_3	68.2 ± 0.55	–
DOC	178 ± 1.7	–
Total solids	20.1 ± 0.5	–
Total phosphorus	28.1 ± 0.9	5,700
Potassium	558 ± 30.5	31,950
Calcium	171 ± 3.1	17,860
Magnesium	256 ± 26.2	6,340
Sodium	319 ± 3.08	–
Manganese	0.05 ± 0	90
Sulphur	43 ± 2.79	8,690
Zinc	0.45 ± 0.02	10
Iron	0.80 ± 0.005	290
Copper	0.85 ± 0.01	10
Boron	0.36 ± 0.01	30
Chloride	572 ± 9.1	–

*Except where stated otherwise.

MATERIALS AND METHODS

Anaerobic effluent

The effluent used in this experiment was from a biodigester treating food and vegetable wastes maintained at Environmental Technology Centre (ETC), Murdoch University. The digester was continuously fed with no stirrer but with natural mixing while feeding, and mesophilic (temperature $<36\ ^\circ C$) in operation. The liquid was collected from the effluent outlet in the digester and stored in an airtight storage tank for the experiment. The liquid effluent was stored at room temperature for about 2 weeks and it was stirred well before application. The characteristics of the effluent used in hydroponic experiment are given below in Table 1.

Experimental set-up

The experiment was conducted in a hydroponic setup made using 20 L plastic containers. The plant pots were inserted in the holes cut in the plastic lid of the container, each container holding six pots. The container was filled with effluent and uniform sized nursery grown silver beet seedlings were planted into the pot containing clay balls to support the seedlings. The setup allowed the roots to grow into the liquid medium in the hydroponic containers for nutrient uptake. No additional watering was done during the experiment.

The experiment was carried out in six different concentrations of anaerobic effluent namely, 5, 10, 15, 20, 30 and 50. The effluent was diluted with deionised water (DI) to get the mentioned concentrations. The control medium used was a commercial hydroponic growth medium (AG-GROW hydroponic nutrient solution, Table 1). It was diluted according to the instructions on the bottle for growing vegetables. Half-strength (5 mL of nutrient solution/L of water) was used during early seedling stage and then, with full-strength (10 mL of nutrient solution/L of water) after 14 days. The liquid medium in the hydroponic containers was changed on the first fortnight, and then every week to prevent any deficiency in nutrients to plants. The water samples were collected on 0th, 14th, 28th and 42nd day. The treatment and control was replicated thrice. The experiment was conducted for 50 days.

Analysis

The plants were observed throughout the experiment for visual appearance and plant growth. The effluent was analysed fortnightly for pH, electrical conductivity (EC), DO, COD, and for nutrients like, nitrate (NO_3), ammonium (NH_4), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). The pH and EC of the liquid were determined using Hanna portable probes. DO was analysed using Hanna DO meter. COD was determined through the dichromate method (APHA 2005) where the effluent was digested for 2 h, and colour formation was measured using calorimeter. The nutrients were analysed using ICP according to Australian standards in a NATA accredited laboratory.

At the end of the experiment, the plants were harvested and measured for various physical and chemical parameters. The height, weight and the nutrients in the plant dry matter were analysed.

RESULTS AND DISCUSSION

The characteristics of the undiluted effluent (100%) are given in Table 1. The 100% effluent had low DO (0.27 mg/L), high NH_4-N (475 mg/L) and significantly high COD (1,258 mg/L). There was complete death of silver beet plants in 50% effluent observed in 2 weeks of starting the experiment. The yellowing of leaves was followed by drying of the foliage and roots. This was believed due to poor oxygen availability to the plant roots, and also the roots exposed to high ammonia concentration in the effluent. Therefore the trial with 50% effluent was discontinued.

Plant parameters

The plants were harvested on 50th day of the experiment and the nutrients determined in plant dry matter are given in Table 2. Total N and P concentration in the plant dry matter was the highest in control than effluent. Among the effluent concentrations, plants grown in 30% effluent had higher N, P and K than the other concentrations of effluent. The plants grown in effluent concentrations, 15, 20 and 30% accumulated more K than control. The plants grown in anaerobic effluent accumulated more Ca and Na in all cases, compared to the control. However, Mg concentration was higher only in 30% effluent when compared to the control. The concentration of these nutrients in plants increased with increased effluent concentration. S and Fe were more in plants from control solution than effluent whereas, Mn was high in 30% concentrated effluent.

It is possible that the risk of heavy metal accumulation is high when wastewater medium is used for plant growth and

Table 2 | Nutrient accumulation in plant dry matter

Nutrients	Control	5%	10%	15%	20%	30%
Total N (%)	2.9 ± 0.07	0.93 ± 0.05	1.16 ± 0.07	1.42 ± 0.02	1.45 ± 0.07	1.76 ± 0.25
P (%)	0.32 ± 0.04	0.061 ± 0.01	0.06 ± 0.0	0.07 ± 0.0	0.07 ± 0.003	0.08 ± 0.00
K (%)	3.12 ± 0.10	2.11 ± 0.06	2.73 ± 0.38	3.23 ± 0.27	3.28 ± 0.05	3.28 ± 0.14
Ca (%)	1.34 ± 0.22	1.41 ± 0.10	2.17 ± 0.10	2.54 ± 0.37	2.71 ± 0.10	2.63 ± 0.25
Mg (%)	1.77 ± 0.03	1.33 ± 0.23	1.59 ± 0.03	1.63 ± 0.07	1.74 ± 0.15	1.92 ± 0.02
Na (%)	2.3 ± 0.03	2.41 ± 0.26	3.38 ± 0.17	4.49 ± 0.14	3.64 ± 0.27	4.04 ± 0.09
S (%)	0.41 ± 0.04	0.32 ± 0.01	0.32 ± 0.025	0.35 ± 0.04	0.31 ± 0.00	0.35 ± 0.02
Fe (mg/kg)	120 ± 12.2	65 ± 0.82	70.5 ± 2.25	84.5 ± 8.97	94 ± 8.33	96.3 ± 1.48
Mn (mg/kg)	82.9 ± 0.27	63 ± 1.12	68.3 ± 1.17	66.5 ± 2.1	76.1 ± 1.68	83.3 ± 0.98
Cu (mg/kg)	2.3 ± 0.3	4.59 ± 0.3	5.12 ± 0.23	5.14 ± 0.09	6.6 ± 0.15	6.65 ± 0.15
Zn (mg/kg)	70 ± 1.77	77.2 ± 6.22	100 ± 7.4	113 ± 6.13	119 ± 3.43	120 ± 5.9

they are accumulated in edible plant parts (Nair *et al.* 2008). In case of silverbeet, foliage being the edible part there is a concern to investigate the concentration of heavy metals accumulated. The results from this study are compared to World Health Organisation (WHO) guidelines, as they are internationally accepted standards, and referenced widely. According to WHO, the maximum recommended concentration of Zn and Cu in edible parts are 400 and 10 mg/kg, respectively (WHO 1996). However, in this study the concentration of Zn in plants was less than 400 mg/kg in all the cases of anaerobic effluent and control. The highest Zn was in foliage from 30% effluent with 120 mg/kg which was well below the maximum recommended level. The Cu concentration was also within the WHO recommended limit of 10 mg/kg with plants grown in the 30% effluent having the highest concentration of 6.6.

The mean wet foliage weight and plant height measured on 50th day of the experiment in each hydroponic container containing 6 plants are illustrated in Figures 1 and 2 respectively. Also, the appearance of plants in control and various anaerobic effluent concentration on 40th day in Figure 2.

The production from the control set up was markedly higher than the effluent treatment systems both in height and weight of the plants (Figures 1 and 2). While the harvest from the control weighed 462 g, 20% effluent with the highest from treatment systems weighed only 38.1 g and followed by 15 and 10% effluent. The plant yield increased with concentration of effluent only till 20% and then decreased with increased concentration of 30%. The foliage weight was lowest in 5% effluent with 9.8 g.

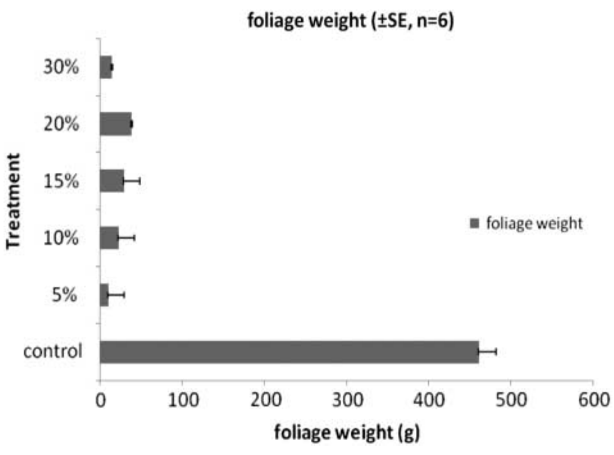

Figure 1 | The wet foliage weight (g) measured at the end of the experiment.

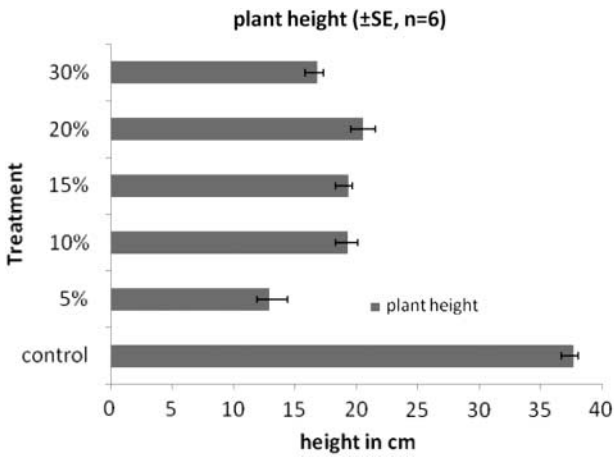

Figure 2 | The plant height (cm) measured at the end of the experiment.

The plant height measured followed the similar trend as foliage weight, with maximum height reached in control (37.7 cm). The plant growth was stunted in all effluent concentrations when compared to control (Figure 3). The plant height was the lowest in 5% effluent (12.9 cm). The height increased with concentration of effluent till 20% (20.6 cm) and then it decreased in the case of 30% (16.8 cm).

The stunted growth in low concentrated effluent is probably due to the lack of nutrients required for plant growth and development, while in the case of 30% effluent low DO concentration may have inhibited the uptake of nutrients required for plant growth. Also, nutrients in the effluent are not in plant available form such as nitrates and phosphates, when compared with ideal proportion of nutrients in the commercial growth medium used as control.

Figure 3 | Appearance of plants on 40th day from left to right: control, 5, 10, 15, 20 and 30%.

Effluent parameters

pH and EC

The initial pH of effluent was in the range of 7.5–7.68, while the control had neutral pH. pH of effluent changed significantly during the experiment (Table 3). An increase in pH was noticed on 14th day in all percentages of effluent and control. Thereafter, there was reduction in pH in 28th day and 42nd day samples. The pH drop was obvious in the final stages of plant growth compared to the initial stages. This could be due to the organic loading in the system from the degradation of roots and plant parts.

The EC of initial effluent was the highest in 30% effluent (2.31 dS/m). EC of the effluent decreased noticeably in the samples analysed fortnightly throughout the experiment (Table 3). The EC of effluent ranged from 0.05 to 1.06 dS/m in the final stages of plant growth which was well below the initial range of 0.71–2.31 dS/m. The silverbeet can be productive up to an EC of 6.35 dS/m (Department of agriculture 1997). The highest EC value recorded in effluent was 2.31 dS/m and therefore salinity of effluent was not a concern for silver beet production.

DO and COD

The DO concentration in initial effluent was highest in 5% effluent and lowest in 30% effluent. The DO changes during the experiment was not uniform. There was decrease in DO on 14th day except in control and 30%, compared to

Table 3 | pH, EC, DO and COD changes during the experiment

	Days	0	14	28	42
pH	Control	7.02 ± 0.01	7.00 ± 0.00	7.04 ± 0.03	7.17 ± 0.12
	5%	7.55 ± 0.01	7.95 ± 0.62	7.45 ± 0.09	7.63 ± 0.24
	10%	7.62 ± 0.03	8.32 ± 0.07	7.55 ± 0.03	7.20 ± 0.06
	15%	7.64 ± 0.032	8.04 ± 0.25	7.42 ± 0.20	7.51 ± 0.17
	20%	7.65 ± 0.035	7.96 ± 0.22	7.43 ± 0.08	7.28 ± 0.12
	30%	7.65 ± 0.02	7.78 ± 0.23	7.46 ± 0.15	7.41 ± 0.11
EC dS/m	Control	1.53 ± 0.03	0.83 ± 0.03	0.23 ± 0.03	0.09 ± 0.01
	5%	0.71 ± 0.01	0.4 ± 0.06	0.13 ± 0.03	0.06 ± 0.01
	10%	1.17 ± 0.02	0.37 ± 0.03	0.17 ± 0.07	0.09 ± 0.01
	15%	1.38 ± 0.001	0.43 ± 0.03	0.3 ± 0.06	0.2 ± 0.06
	20%	1.70 ± 0.001	0.73 ± 0.03	0.27 ± 0.03	0.2 ± 0.1
	30%	2.31 ± 0.05	1.47 ± 0.22	0.37 ± 0.03	0.17 ± 0.07
DO mg/L	Control	9.04 ± 0.03	9.08 ± 0.03	7.9 ± 0.1	7.87 ± 0.26
	5%	7.53 ± 0.27	6.0 ± 0.06	6.47 ± 0.22	6.53 ± 0.14
	10%	6.44 ± 0.12	5.8 ± 0.06	6.6 ± 0.12	6.53 ± 0.23
	15%	6.17 ± 0.07	5.87 ± 0.12	6.1 ± 0.1	6.23 ± 0.54
	20%	5.72 ± 0.20	5.43 ± 0.37	5.63 ± 0.07	6.07 ± 0.09
	30%	3.72 ± 0.58	4.37 ± 0.27	5.5 ± 0.30	5.5 ± 0.38
COD mg/L	Control	14.67 ± 1.45	108.3 ± 23.6	21.7 ± 2.4	1 ± 1
	5%	115 ± 14.8	231.3 ± 19.4	76.3 ± 4.8	12.3 ± 2.4
	10%	202 ± 13.5	457 ± 3.05	165 ± 22.03	16.7 ± 6
	15%	300 ± 3.9	160 ± 7.8	73 ± 25.8	11 ± 6
	20%	300 ± 43.6	269 ± 16.5	31.7 ± 5.7	14 ± 2.1
	30%	437 ± 7	260 ± 3.21	118 ± 27.9	36.3 ± 18

initial DO concentration. On 28th day, there was decrease in DO concentration except in 10 and 30%, and on 42nd day analysis, there was increase in DO concentration in all concentration of effluent except control. DO concentration of the 30% effluent increased on all days of the experiment. The crop production requires a minimum DO of 0.5 mg/L (Angelakis *et al.* 1999) and the DO concentration was more than 0.5 mg/L in all concentration of effluent during the experiment (Table 3).

COD of initial effluent concentrations increased with the proportion of effluent (Figure 4 and Table 3). The initial COD was the highest in 30% effluent (437 mg/L). During the experiment the COD reached the maximum on 14th day in control, 5 and 10% and thereafter, there was a drop on 28th and 42nd day. In the remaining concentrations of the effluent there was a gradual decrease in COD concentration throughout the experiment. There was increase or only a slight decrease in COD noticed during the very early stages of plant growth followed by a remarkable decrease. This proves that hydroponic plant growth system can effectively reduce the COD concentration in the anaerobic effluent.

In effluent treatment, the physiological conditions created by the plants tend to be a stabilising factor in comparison with conditions created by bacteria alone and this was proved in case when water hyacinth treatment system was found effective than activated sludge system in effluent treatment (Norstrom 2005). The plant roots may provide suitable substrate for the growth of microorganisms which will increase the treatment of effluent. There was 88–96% reduction in COD of the effluent in hydroponic medium.

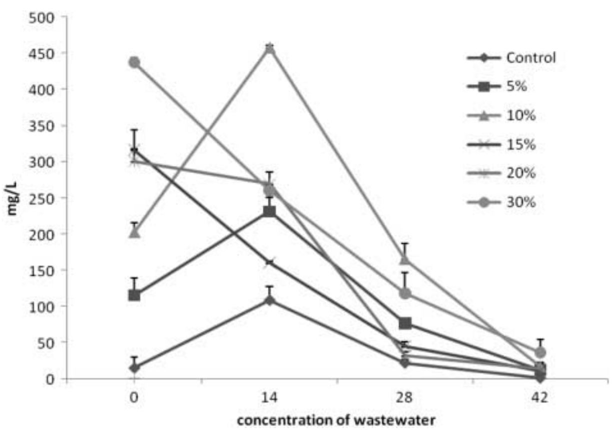

Figure 4 | Changes in COD at differenct concentrations of the medium during the experiment.

Nutrient changes

The plants used nutrients in the effluent for their growth and development. The control medium was a commercial hydroponic solution and it supplied the required nutrients to the plant growth with perfect mix of nutrients. The nutrient solution was replaced weekly, except for the first time, where it was replaced fortnightly. The initial concentration of the solution added every week was considered similar to the 0th day concentration, both in control and treatment.

The ammonium concentration in the hydroponic medium decreased, probably due to aeration of the medium and utilisation of nutrients by the plants. The nutrient uptake rate changed according to the plant growth stage. The ammonium conversion by plants was more during 28th and 42nd of experiment compared to early stages of plant growth when the foliage growth was increasing. After 42 days the level of ammonium came down to 0.5 mg/L in the 30% concentration and it was similar to control in 20% concentrated effluent.

The uptake of nitrate increased with the growth of the plant (Table 4). Similar to ammonium, there was higher utilisation of nitrate on 28th and 42nd day of the experiment compared to initial 2 weeks which can be well understood by low nitrate concentration in the samples analysed. The nitrate utilisation from anaerobic effluent was not as efficient as the commercial medium. It was believed that low oxygen concentration in anaerobic effluent would have inhibited nutrient uptake and therefore the plant growth in effluent was retarded which is explained below.

The initial phosphorus concentration in effluent was lesser when compared to other nutrients (Table 4). Phosphorus followed similar trend as nitrates. As the growth of plants increased, the uptake of P increased. Phosphorus uptake was more on 42nd day of the experiment when compared with 14th and 28th day.

The initial potassium concentration in 30% effluent was more than the control. The utilisation of potassium increased with the growth of silverbeet. However plants in

Table 4 | The nutrient changes in hydroponic medium during the experiment

	Days	0	14	28	42
NH_4 mg/L	Control	8.39 ± 0.08	3.76 ± 0.03	6.97 ± 0.2	0.37 ± 0.11
	5%	23.03 ± 0.06	1.45 ± 0.38	0.24 ± 0.04	0.25 ± 0.01
	10%	30.83 ± 0.02	0.10 ± 0.00	0.63 ± 0.24	0.91 ± 0.47
	15%	37.7 ± 0.21	0.10 ± 0.00	0.24 ± 0.04	0.42 ± 0.02
	20%	42.7 ± 0.02	0.09 ± 0.20	1.67 ± 0.75	0.35 ± 0.03
	30%	46.5 ± 0.04	11.46 ± 3.83	1.43 ± 0.75	0.50 ± 0.16
NO_3 mg/L	Control	153 ± 1.92	48.6 ± 0.16	25.4 ± 7.14	0.62 ± 0.01
	5%	7.37 ± 0.03	2.29 ± 0.05	1.13 ± 0.03	0.14 ± 0.03
	10%	9.52 ± 0.04	2.49 ± 0.01	2.33 ± 2.19	0.2 ± 0.05
	15%	12.69 ± 0.01	3.65 ± 0.01	3.54 ± 0.03	1.4 ± 0.01
	20%	18.61 ± 0.05	4.1 ± 0.07	3.73 ± 0.04	2.68 ± 0.2
	30%	47.0 ± 0.17	34.1 ± 1.13	20.16 ± 4.68	13 ± 1.65
P mg/L	Control	26.3 ± 0.11	6.9 ± 0.57	4.93 ± 1.35	1.57 ± 0.71
	5%	0.62 ± 0.01	0.43 ± 0.09	0.33 ± 0.12	0.10 ± 0.03
	10%	0.92 ± 0.01	0.52 ± 0.17	0.39 ± 0.07	0.16 ± 0.08
	15%	1.37 ± 0.02	0.81 ± 0.09	0.65 ± 0.19	0.17 ± 0.24
	20%	1.92 ± 0.01	1.09 ± 0.21	0.94 ± 0.04	0.28 ± 0.24
	30%	2.74 ± 0.01	3.53 ± 0.05	1.55 ± 0.16	1.47 ± 0.64
K mg/L	Control	132.1 ± 0.85	66.1 ± 7.2	28.2 ± 8.65	15.02 ± 1.6
	5%	34.8 ± 0.15	15.5 ± 1.34	12.8 ± 1.51	8.27 ± 0.59
	10%	51 ± 0.3	24.5 ± 2.14	14.5 ± 2.0	16.5 ± 1.8
	15%	75.1 ± 0.56	34.5 ± 1.65	22.3 ± 3.12	14.3 ± 2.04
	20%	103 ± 0.14	149 ± 3.4	113 ± 11.3	145 ± 8.6
	30%	141 ± 0.58	201 ± 1.55	191 ± 4.74	219 ± 2.02

10, 20, 30 and 50% effluent used less potassium on 42nd day than on 28th day.

The effluent from anaerobic digestion process is well supplied with calcium and magnesium. 20 and 30% effluent had higher magnesium than control. Similar to other nutrients, the utilisation of Ca and Mg was higher in later stages of silver beet growth (Table 5). The samples analysed on 42nd day showed the highest Ca and Mg utilisation than other days.

The heavy metal concentration like copper and zinc was less than the detectable range of the measuring instrument and hence it was not reported. The heavy metal concentration in the anaerobic effluent was also not recorded high, because the digester used the effluent only from the food waste from supermarkets to produce biogas and effluents.

Agronomic effects

Hydroponics can be used for wastewater reuse as it contains nutrients required for plant growth (Keller *et al.* 2008). The nutrients in the wastewater may result in eutrophication in receiving water bodies and the hydroponic medium was found to treat the nutrients effectivly through plant uptake. However, the plant growth studied in this experiment suggested that the plant production in anaerobic digestate alone, is not a viable option due to highly retarded growth in effluent when compared with control. The effluents from fish water tank effluent, pig slurry, stormwater, sewage water, human urine, municipal sewage, secondary treated wastewater were researched to grow plants as a hydroponic medium (Oyama 2008).

Table 5 | Ca and Mg changes during the experiment

	Days	0	14	28	42
Ca mg/L	Control	75.13 ± 1.01	51.27 ± 1.51	35.4 ± 3.11	25.8 ± 3.4
	5%	19.2 ± 0.11	14.83 ± 2.4	13.13 ± 0.74	12.8 ± 0.80
	10%	24.6 ± 0.31	17 ± 2.23	16.3 ± 0.71	13.6 ± 1.2
	15%	31.9 ± 0.43	23.1 ± 3.1	22.07 ± 1.54	14.2 ± 2.0
	20%	40.9 ± 0.44	33.7 ± 2.2	26.2 ± 2.75	25.0 ± 0.22
	30%	54.2 ± 0.17	33.4 ± 2.54	32.9 ± 1.8	23.7 ± 1.77
Mg mg/L	Control	40 ± 1.6	28.9 ± 0.5	21.1 ± 2.7	10.6 ± 3.21
	5%	23.4 ± 1.5	17.2 ± 2.4	10.5 ± 2.6	7.9 ± 1.11
	10%	31.18 ± 1.5	25.9 ± 2.07	15.6 ± 0.52	13.7 ± 2.14
	15%	39.3 ± 0.87	26.3 ± 2.37	17.1 ± 1.49	15.8 ± 1.0
	20%	51.13 ± 1.32	27.63 ± 1.81	23.32 ± 1.18	19.07 ± 0.86
	30%	69.4 ± 1.32	65 ± 0.72	47.1 ± 2.52	31.27 ± 2.7

There are also limited research on using anaerobic effluent as a medium for hydroponic cultivation. Keller *et al.* (2008) evaluated the growth of lettuce grown with effluent from anaerobic reactor and polishing pond followed by physical–chemical treatment and found it as a suitable complement for hydroponic cultivation. Also, Liedl *et al.* (2006) found that application of digested liquids from poultry wastes on grass and vegetable fields resulted in higher yield than commercial N fertilisers. Further, in hydroponic production lettuce produced comparable yield to commercial hydroponic nutrient solution whereas, the yield was reduced in tomato due to requirement of supplementation and conversion of ammonium to nitrate.

The plants grown in hydroponic medium may experience diffusion limitations compared to plants grown in soil substrate, where the roots get sufficient oxygen. Oxygen deficiency inhibits cell respiration and hence the nutrient absorption and biomass production are highly affected (Norstrom 2005). As the anaerobic effluent was oxygen deficient, the nutrient use efficiency and therefore plant growth was reduced.

It is clear from this study that the original effluent is not a suitable substrate for plant growth due to low DO concentration and ammonium toxicity. Also, the dilution with fresh water neither yielded quality crop production to match the commercial nutrient solution. Therfore, physical, chemical or biological pre-treatment of the effluent should be considered before integration with hydroponic cultivation. Therafter, there is a possibility to convert effluent into a valuable crop nutrient resource. The effluent studied by itself is not suitable for commercial hydroponic cultivation, however, there was effective treatment of the effluent.

The anaerobic effluent for this study was sourced only from a single digester treating food and vegetable wastes with effluent characteristics described in Table 1. The nature of digestate may depend on type of feed stock used for anaerobic digestion and digestion conditions (temperature, retention time, pH, stage). Therefore, the results produced need verification on plant growth and treatment depending on the characteristics of digestate.

CONCLUSION

There was effective COD reduction (86–97%) during hydroponic treatment of anaerobic effluent. This method therefore could be a ecologically sustainable method to remove nutrients from the effluent and reduce pollution of receiving water bodies. From the results it is clear that the growth of silverbeet was not comparable with control medium due to inadequate uptake of nutrients to the plants. The plants grown in 20% effluent had the highest foliage weight and plant height compared to other concentration. The results suggest that dilution of anaerobic effluent is necessary for irrigation purposes with anaerobic effluent especially in hydroponic system. However, its utilisation in field conditions need further research.

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