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The potential use of treated brewery effluent as a water and nutrient source in irrigated crop production

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ABSTRACT

Brewery effluent (BE) needs to be treated before it can be released into the environment, reused or used in down-stream activities. This study demonstrated that anaerobic digestion (AD) followed by treatment in an integrated tertiary effluent treatment system transformed BE into a suitable solution for crop irrigation. Brewery effluent can be used to improve crop yields: Cabbage (*Brassica oleracea* cv. Star 3301), grew significantly larger when irrigated with post-AD, post-primary-facultative-pond (PFP) effluent, compared with those irrigated with post-constructed-wetland (CW) effluent or tap water only ($p < 0.0001$). However, cabbage yield when grown using BE was 13% lower than that irrigated with a nutrient-solution and fresh water; the electrical conductivity of BE (3019.05 ± 48.72 μs/cm^2) may have been responsible for this. Post-CW and post-high-rate-algal-pond (HRAP) BE was least suitable due to their higher conductivity and lower nutrient concentration. After three months, soils irrigated with post-AD and post-PFP BE had a significantly higher sodium concentration and sodium adsorption ratio (3919 ± 94.77 & 8.18 ± 0.17 mg/kg) than soil irrigated with a commercial nutrient-solution (920.58 ± 27.46 & 2.20 ± 0.05 mg/kg). However, this was not accompanied by a deterioration in the soil's hydro-physical properties, nor a change in the metabolic community structure of the soil. The benefits of developing this nutrient and water resource could contribute to cost-reductions at the brewery, more efficient water, nutrient and energy management, and job creation. Future studies should investigate methods to reduce the build-up of salt in the soil when treated BE is used to irrigate crops.

1. Introduction

Brewery effluent (BE) is an organic effluent that contains nitrogen and phosphorus, and a range of organic and inorganic compounds [30,32]. These nutrients are essential for plant growth and health so brewery effluent has the potential to be used as a source of water and nutrients in irrigated crop production [10,26,32]. However, BE also has properties that inhibit the growth of plants and deteriorate soil physical profile and fertility when used to irrigate crops [16,17,8].

Brewery effluent at Ibhayi Brewery (SAB (Pty) Ltd, Port Elizabeth, South Africa) is treated in an anaerobic digester (AD) and activated sludge system before being either piped to a municipal sewer or channelled back to the factory for re-use in non-production activities. A small stream of post-AD BE is fed into an experimental treatment facility, which uses various alternative, sustainable methods of bioremediation including a primary-facultative-pond (PFP), a high-rate-algal-pond (HRAP) and a constructed-wetland

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(CW). Each treatment process results in BE with different water quality parameters such as pH, form and concentration of nitrogen, and the concentration of phosphorus, sodium and other dissolved salts [14]. These parameters have been shown to directly and indirectly affect plant growth and soil fertility ([21], [30]).

Different methods of BE pre-treatment have been found to influence nutrient availability and downstream crop productivity [30]. Furthermore, the sodium concentration of BE negatively affected the physical properties of the irrigated soil [8]. It is therefore essential that the most effective pre-treatment method of BE is found so that the nutrients in the effluent are made accessible to the plants while minimising any negative impacts BE may have on the soil.

1.1. Aims and objectives

The aim of this study was to determine the suitability of different tertiary effluent technologies in making BE suitable for crop irrigation. This was done by comparing the change in soil characteristics and growth of cabbages irrigated with BE drawn at various points from an experimental BE treatment system including post-AD, post-PFP, post-HRAP and post-CW to cabbages irrigated with tap water or a combination of water and inorganic-fertilizer.

2. Methods and materials

2.1. Experimental species and system

Cabbage (*Brassica oleracea*) was used as the test crop because it has similar salt tolerance and nutrient requirements as most vegetables [29]. Two hundred cabbage seedlings (*Brassica oleracea* cv. Star 3301; Starke Ayres Pty Ltd, South Africa) were purchased from a commercial nursery (Moorland Seedlings Pty Ltd, Humansdorp, South Africa). Of these 120 similar size seedlings were used in this experiment.

Cabbage plants were grown out doors in 23 l pots. These pots were filled with an oxidic sandy loam top soil (10% silt, 20–25% clay, 65–70% sand) classified according to Macvicar et al. [22]. One cabbage plant was planted in each pot.

2.2. Treatments

Six irrigation solutions were applied to the cabbages, which included post-AD, post-PFP, post-HRAP, post-CW, a nutrient-solution (NS) and municipal water. The pH of each treatment was either adjusted to 6.5 with 98% sulphuric acid (Protea Chemicals Pty Ltd, South Africa) or left unadjusted (Table 1).

The plants irrigated with tap water served as a control. The nutrient-solution was comprised of a commercially available inorganic-fertilizer (Hygrotech Pty Ltd, South Africa; Registration number K5709; Act 36 of 1947), and calcium nitrate with a composition of 11.7% nitrogen and 16.6% calcium, mixed in a ratio of 1:0.8 and dissolved in municipal water to achieve an electrical conductivity (EC) of 1800 μm (Hygrotech Pty Ltd, South Africa). Each treatment was replicated ten times with a replicate consisting of a single plant in a pot.

2.3. Irrigation regime and pest control

Cabbages were irrigated with one litre two to three times a week. During irrigation care was taken not to wet the cabbage leaves. The maximum volume of water irrigated at one time was one litre. This was done to ensure that leaching did not occur. Water was not observed draining out the bottom of the pots. In total each cabbage plant received 198.1 mm of treatment water and 91 mm of rain during the twelve week growth trial.

One month after planting, diamond back moth larvae were noticed on some of the cabbages. Cabbages plants were sprayed with Malasol (active ingredient: mercaptothion, Efekto Agro-Serve Pty Ltd) to kill the larvae. When a spraying occurred every plant was sprayed, an event that occurred five times during the trial. No plants suffered severe damage from the diamond back moth larvae.

Table 1
Irrigation treatments (T1-T12) that were used to irrigate cabbage plants.

Irrigation solution	pH not adjusted	pH adjusted to 6.5
AD effluent	T1	T7
PFP effluent	T2	T8
HRAP effluent	T3	T9
CW effluent	T4	T10
Municipal water	T5	T11
Municipal water with inorganic fertiliser	T6	T12

Anaerobic digestion (AD), primary-facultative-pond (PFP), high-rate-algal-pond (HRAP), constructed-wetland (CW).

2.4. Data collection

2.4.1. Irrigation water chemistry

The pH, temperature and EC of the water used in each treatment were recorded before each irrigation using an electronic probe (Hanna, HI 991300, United Kingdom). Chemical oxygen demand (COD), ammonia, nitrite, nitrate and phosphate of each irrigation solution was recorded weekly, using a spectrophotometer (Merck Spectroquant Pharo 100 spectrophotometer, product number 100706, Darmstadt, Germany) and commercially available test kits, using standard methods (Merck Pty Ltd, products: 1.14559.0001, 1.14752.0001, 1.14776.0001, 1.09713.0001, 1.14842.0001, 1.14895.0001). Each sample was filtered through an eight micron filter paper prior to analysis to remove suspended solids.

2.4.2. Plant productivity

At the beginning of the trial the mass of each plant planted in the pots was recorded (0.1 g). At the end of the trial the mass of each plant was also recorded (0.1 g). The chlorophyll concentration index (CCI) of cabbage plant leaves was recorded using a chlorophyll concentration meter (CCM-200 Plus Chlorophyll Concentration Meter, Opti-Sciences Inc., USA). Readings were recorded at the start of the trial and every four weeks until the end of the experiment, on the uppermost fully expanded leaf of each plant.

At the beginning of the trial 12 plants were randomly chosen and used for leaf chemical analysis. These plants were not used in the experiment due to the destructive nature of the sampling. At the end of the three pots were randomly selected from each treatment and plants used for leaf chemical testing. All samples were analysed for N, P, K, Na, and Cl concentration at a commercial analytical laboratory (BemLab Pty Ltd, Strand, South Africa).

Photographs of the plants and stress symptoms were recorded to monitor nutrient deficiencies. Daily temperature and rainfall data were recorded using a rainfall gauge and a thermometer (Hanna, HI 991300, United Kingdom) situated next to the experimental area.

2.4.3. Soil monitoring

Air filled porosity (AFP), bulk density and moisture concentration were measured, in each pot at the beginning and end of the trial, according to the Australian standard for potting mixes [12]. Infiltration rates were determined, every four weeks, by pouring one litre of treatment water into each pot in twenty seconds and recording the time it took for the water to drain into the soil. Timing started once all the water had been poured into the pot. Infiltration rate was then calculated (Eq. (1)):

$$\text{Infiltration rate} = (\text{volume of water added}/\text{surface area of pot})/\text{time} \tag{1}$$

Soil aggregate stability was measured at the beginning and end of the experiment on five grams of 2–5 mm aggregates [20]. At the start, 10 samples were taken from the soil used to fill the pots. At the end of the trial soil samples from five pots were randomly selected from each treatment. Five grams of soil sample was placed in distilled water and allowed to stand for ten minutes. The sample was then passed through a 0.05 mm sieve and aggregates $>$ 0.05 mm were collected and transferred onto a 0.50 mm sieve previously immersed in ethanol, and shaken five times with a gentle regular helical rotation movement. The $>$ 0.5 mm aggregates on the sieve were collected, dried at 40 °C, and then gently dry sieved using a column of six sieves: 2.00, 1.00, 0.50, 0.20, 0.10, and 0.05 mm. The aggregate stability was represented by the mean weight diameter (MWD) of aggregates and was calculated using Eq. (2):

$$\text{Mean weight diameter} = \sum (\text{d x m})/100 \tag{2}$$

where d was the mean diameter between the two sieves (mm) and m was the weight fraction of aggregates remaining on the sieve (%).

A psychrometer (PST-55–15 thermocouple psychrometer/hygrometer, Psypro, Wescor Inc., Logan, UT, USA) was used to construct a soil suction test, which related gravimetric soil water concentration to soil water potential. At the beginning of the trial 10 samples were taken from the soil used in the trial. At the end of the trial soil samples from four pots were randomly selected from each treatment. Each sample was analysed at 30%, 20% and 10% gravimetric soil water concentration.

Electrical conductivity and pH were measured in every pot at the start and end of the experiment using a pH and conductivity meter (Hanna, HI 991300, United Kingdom) where the soil sample was mixed with distilled water at a ratio of 1:2.5 .

At the beginning of the trial 10 samples were taken from the soil used in the trial and used for soil chemical analysis. At the end of the trial three random soil samples were taken from each treatment. A sample consisted of soil taken from one pot. Soil samples were sent to a commercial analytical laboratory and analysed for CEC, C, Cl, Na, K, Ca, and Mg (BemLab Pty Ltd, Strand, South Africa). The sodium adsorption ration of the soil was calculated using Eq. (3), where Na, Ca, Mg and K are expressed in millequivalents per litre, (meq/l) obtained from a saturated paste soil extract [36].

$$\text{Sodium adsorption ration} = \text{Na} \div \sqrt{\frac{\text{Ca} + \text{Mg}}{2}} \tag{3}$$

Community level physiological profiling was used to describe the biological health of the soil. Soil samples were directly inoculated into single carbon source wells of microtitre plates (Eco Microplates BL1506, Biolog Inc, USA), followed by incubation and spectrometric detection of heterotrophic activity [11]. At the beginning of the trial 12 samples were randomly taken from the soil before it was placed into the pots. At the end of the trial soil from three randomly selected pots was used for analysis. One gram of soil sample was suspended in sterile saline solution (0.2% NaCl) and diluted to give a final 10^{-3} dilution. After mixing, 150 µl was pipetted into each of the wells in the microtitre plates. The plate was then incubated at 25 °C and readings were taken every 24 h, for five days, using a microplate reader (PowerWave HT Microplate Spectrophotometer, Biotek, USA) at a wavelength of 590 nm.

Microbial activity in each plate was expressed as average well colour development (AWCD) and was determined using Eq. (4) (Garland & Millis 1991, Gomez *et al.* 2004):

$$\text{Average well colour development} = \sum \text{OD}_i/31 \quad (4)$$

where OD_i was the optical density from each well, corrected by subtracting the blank well (inoculated, but without a carbon source) from each plate well (Garland & Millis 1991, [39]). Richness (R) was calculated as the number of wells with a positive optical density (the number of oxidised carbon substrates, [23]). Shannon-Weaver index (H) was calculated using Eq. (5):

$$\text{Shannon} - \text{Weaver index} = -\sum p_i(\ln p_i) \quad (5)$$

where p_i was the ratio of the activity on each substrate (OD_i) to the sum of activities on all substrates (ΣOD_i; Garland & Millis 1991, [23]). Plate reading at 119 h of incubation were used to calculate AWCD, R and H. The carbon substrates on each plate were grouped into the following five categories: (1) carbohydrates; (2) carboxylic and acetic acids; (3) amino acids; (4) polymers; and (5) amines and amides [39]. Each category was expressed as a percentage of total absorbance of the plate corresponding to a particular treatment [39].

Microbial counts from the same 10^{-3} soil dilution were also conducted on nutrient agar plates using a spread plating method and 100 µl inoculum. Plates were then incubated at 25 °C for 24 h and the number of colonies on each plate was counted and colony forming units (CFU) were calculated using Eq. (6).

$$\text{CFU} = \text{number of colonies}.10^4 \quad (6)$$

2.5. Statistical analysis

Treatment means were compared using a one-way or a multi-factor analysis of variance (ANOVA) and a Tukey's multiple range analysis at $p < 0.05$. Data collected over the course of the trial were compared using a one-way or a multifactor repeated measures ANOVA ($p < 0.05$). All data were checked for equality of variance and for the normal distribution of the residuals using Levene's test and a Shapiro-Wilk plot of the residuals, respectively. If the assumptions were not met then the data were log or square-root transformed and checked for equal variance and normal distribution of residuals. If the assumptions were still not met, a non-parametric Mann-Whitney *U* test or a Kruskal-Wallis ANOVA was used to compare the data between treatments. All analyses were performed using the Statistica (version 10) software package (StatSoft Inc, Tulsa, USA).

3. Results

3.1. Irrigation water chemistry

The conductivity of the BE treatments (3301.85 ± 34.46 µs/cm^2) was significantly higher than the nutrient-solution (1904.91 ± 31.10 µs/cm^2) and water-only (595.86 ± 17.466 µs/cm^2) treatments (Kruskal-Wallis, $H_{(11,264)} = 239.57$, $p < 0.0001$; Fig. 1). The conductivity increased for all treatments when the pH was adjusted to 6.5 (Fig. 1). Brewery effluent treatments had a higher pH than the nutrient-solution and water treatments (Fig. 2). Post-HRAP effluent had the highest pH (9.17 ± 0.14) while the other BE treatments had a mean pH of 8.14 ± 0.03 (Fig. 2). The ammonia-nitrogen concentration of the nutrient-solution

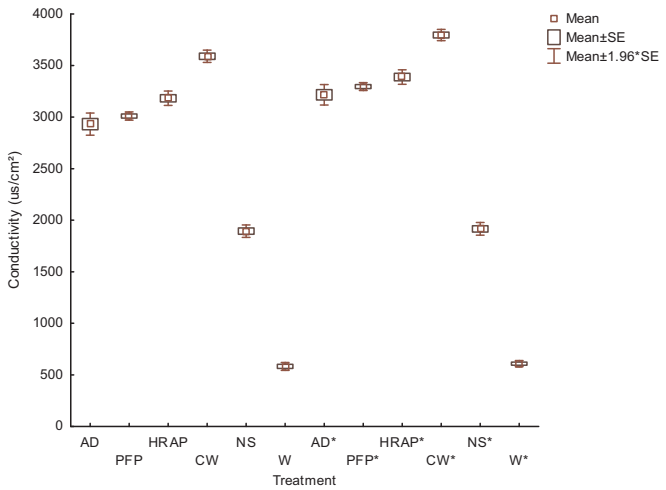

Fig. 1. The mean electrical conductivity of the irrigation treatments: anaerobic digestion (AD), primary-facultative-pond (PFP), high-rate-algal-pond (HRAP), constructed-wetland (CW), nutrient-solution (NS) and water (W) (Kruskal-Wallis, $H_{(11,264)} = 239.57$ $p < 0.0001$). The irrigation water of treatments marked with * were subject to pH adjustment.

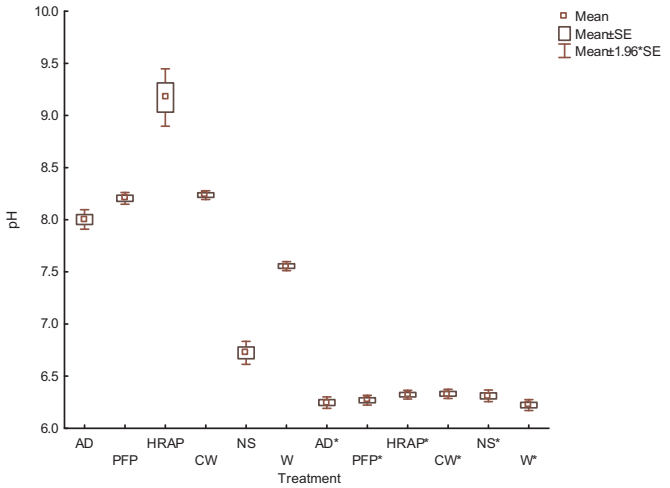

Fig. 2. The mean pH of the irrigation treatments: anaerobic digestion (AD), primary-facultative-pond (PFP), high-rate-algal-pond (HRAP), constructed-wetland (CW), nutrient-solution (NS) and water (W). The irrigation water of treatments marked with * were subject to pH adjustment.

(17.64 ± 0.69 mg/l) was lower than the AD and PFP (34.74 ± 2.18 mg/l) treatments but higher than the water, HRAP and CW treatments (Kruskal-Wallis, $H_{(5162)} = 141.30$, $p < 0.0001$; Table 2). The nitrate and phosphate concentrations were highest in the nutrient-solution, AD and PFP treatments (Table 2). The HRAP, CW and treatments had the lowest nitrate and phosphate concentration (Table 2).

3.2. Plant productivity

The final mass of cabbages was not influenced by an interaction between pH regime and water source (Multifactor-ANOVA, $F_{(5108)} = 0.93$, $p = 0.46$; Fig. 3). The pH adjustment of the treatments did not affect the final mass of the cabbage plants (Multifactor-ANOVA, $F_{(1108)} = 2.83$, $p = 0.10$), whereas there was a significant difference in the final weight of crops irrigated with water from different sources (Multifactor-ANOVA, $F_{(1108)} = 446.12$, $p < 0.0001$). Cabbage plants irrigated with NS had the greatest mass (1223.32 ± 40.98 g) followed by cabbage plants irrigated with AD and PFP BE (478.13 ± 17.39 g; Fig. 3). The AD, PFP and HRAP treatments resulted in cabbages that were significantly larger than those grown using water-only (Fig. 3). The mass of cabbage plants irrigated with CW effluent and water-only were the smallest, with no significant difference in plant weight between them (Fig. 3). The CCI of cabbage plants was not influenced by an interaction between pH regime and the water source (Multifactor repeated measures ANOVA, $F_{(15,321)} = 0.63$, $p = 0.85$). The pH adjustment of the water sources had no effect on the CCI of cabbage plants (Multifactor repeated measures ANOVA, $F_{(5107)} = 1.15$, $p = 0.34$). There was a significant difference in the CCI of cabbages irrigated with the various water sources, with the NS irrigated cabbages having the highest CCI, followed by AD and PFP irrigated cabbages (Multifactor repeated measures ANOVA, $F_{(15,321)} = 25.41$, $p < 0.0001$; Fig. 4). Cabbages irrigated with water, HRAP and CW effluent had the lowest CCI values over the course of the trial (Fig. 4).

3.3. Chemical characteristics of plants

Cabbage plants irrigated with NS had significantly higher concentrations of N, P and K in their leaf tissue than cabbages subject to any of the BE treatments (Kruskal-Wallis, $p < 0.05$; Table 3). The leaf concentration of N, P and K was similar for cabbages irrigated

Table 2
The mean (± standard error) water quality parameters of the irrigation treatments. Means in the same row with a different superscript are significantly different (Kruskal-Wallis, $P < 0.05$).

Property	Treatment							
	AD	PFP	HRAP	CW	NS	Water	H	P
COD(mg/l)	183.07 ± 9.49^{a}	164.26 ± 7.42^{a}	135.04 ± 8.52^{a}	141.30 ± 5.38^{a}	18.85 ± 1.09^{b}	16.00 ± 0.32^{b}	114.27	< 0.0001
NH_4-N(mg/l)	33.68 ± 2.58^{a}	35.75 ± 1.78^{a}	2.52 ± 0.19^{b}	2.14 ± 0.34^{b}	17.04 ± 0.69^{c}	0.70 ± 0.05^{b}	141.30	< 0.0001
NO_3-N(mg/l)	22.96 ± 0.51^{a}	18.79 ± 1.29^{a}	9.21 ± 0.69^{b}	7.87 ± 0.53^{b}	25.01 ± 0.87^{a}	5.07 ± 0.45^{b}	124.34	< 0.0001
PO_4-P(mg/l)	27.09 ± 0.97^{a}	25.61 ± 1.05^{a}	16.12 ± 0.95^{b}	17.31 ± 0.93^{b}	29.88 ± 0.12^{a}	6.13 ± 0.45^{c}	124.51	< 0.0001
Chloride(mg/l)	151.92 ± 4.82^{a}	153.07 ± 4.75^{a}	166.85 ± 5.13^{ab}	189.07 ± 4.69^{b}	81.78 ± 1.77^{c}	80.70 ± 1.67^{c}	119.30	< 0.0001

Anaerobic digestion (AD), primary-facultative-pond (PFP), high-rate-algal-pond (HRAP), constructed-wetland (CW), nutrient-solution (NS). Chemical oxygen demand (COD).

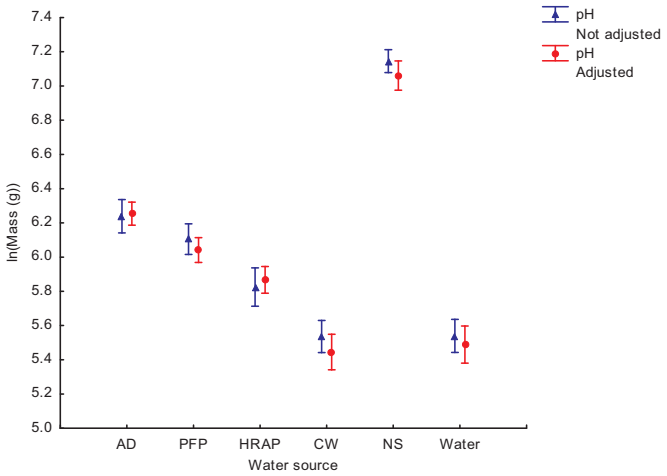

Fig. 3. The mean (± 95% confidence interval) log transformed mass of cabbages subject to irrigation treatments after 12 weeks: anaerobic digestion (AD), primary-facultative-pond (PFP), high-rate-algal-pond (HRAP), constructed-wetland (CW), nutrient-solution (NS) and water (Multifactor-ANOVA, $F_{(5108)} = 0.93$, $p = 0.46$).

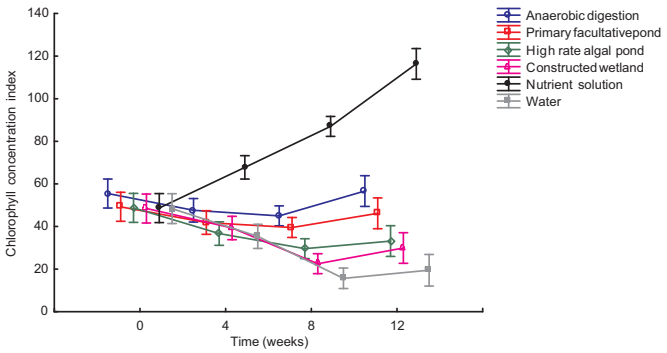

Fig. 4. The mean (± 95% confidence interval) chlorophyll concentration index of cabbages subject to irrigation treatments over the 12-week trial (Multifactor repeated measures ANOVA, $F_{(15,321)} = 25.41$, $p < 0.0001$).

under all the BE and water treatments (Table 3). The pH adjustment of the treatments had no effect on the N, P and K concentration of cabbage leaves (Table 3).

The Na concentration of cabbage leaves was not influenced by pH, and the interaction between pH regime and water source (Multifactor-ANOVA, $F_{(5,24)} = 0.85$, $p = 0.53$; Table 3). Cabbages plants irrigated with water had the lowest Na leaf concentration while cabbage plants subject to the rest of the treatments had similar Na leaf concentrations (Table 3). The pH adjustment of the irrigation solutions decreased the Na leaf concentration of cabbage plants (Multifactor-ANOVA, $F_{(1,24)} = 17.48$, $p = 0.0003$). There was no difference in the chloride leaf concentration of cabbage plants subject to all twelve treatments (Multifactor-ANOVA, $F_{(1,24)} = 2.07$, $p = 0.10$; Table 3).

3.4. Soil physical characteristics

The water potential of soils was not influenced by an interaction between pH regime and water source (Multifactor repeated measures ANOVA, $F_{(10,72)} = 0.24$, $p = 0.99$). The pH of treatments did not influence the water potential of soils (Multifactor repeated measures ANOVA $F_{(2,72)} = 1.06$ $p = 0.35$). The water potential of soils receiving HRAP and CW treatments was consistently lower than soils subject to the other treatments (Multifactor repeated measures ANOVA $F_{(10,72)} = 45.64$, $p < 0.0001$; Fig. 5). The difference in soil water potential of soils receiving the treatments became more pronounced as the soil moisture concentration decreased (Fig. 5). Soils receiving AD, PFP, NS and water treatments had similar water potentials at all soil moisture concentrations (Fig. 5).

Mean weight diameter was not influenced by an interaction between pH regime and treatment (Multifactor-ANOVA, $F_{(5,36)} = 0.65$, $p = 0.66$; Table 4). The pH adjustment of the treatments had no effect on the MWD of the soil particles (Multifactor-ANOVA, $F_{(5,36)} = 0.26$, $p = 0.61$). Soils irrigated with AD, NS and water treatments had a higher mean diameter than soils irrigated with BE after PFP, HRAP and CW treatments (Multifactor-ANOVA $F_{(5,36)} = 26.22$, $p < 0.0001$). The interaction between pH regime and water source significantly influenced the infiltration rate of the soil (Multifactor-ANOVA, $F_{(5108)} = 4.10$, $p = 0.002$; Table 4). The infiltration rate of soils receiving AD, PFP and NS treatments was higher than soils subject to HRAP, CW and water treatments (Table 4). The pH of treatments did not influence the infiltration rate of the soil, with the exception of the PFP treatments (Table 4).

Table 3
The mean (± standard error) leaf chemical concentration for cabbage plants subject to the different irrigation treatments, after 12 weeks. Means in the same row with a different superscript are significantly different (Multifactor-ANOVA/Kruskal-Wallis, $P < 0.05$).

	Treatment						
Element	AD	PFP	HRAP	CW	NS	Water	AD*
Chloride(g/kg)	2.0 ± 0.4	1.9 ± 0.5	2.2 ± 0.2	1.5 ± 0.4	1.4 ± 0.3	2.1 ± 0.2	1.3 ± 0.03
Nitrogen(g/kg)	18.6 ± 0.5^{a}	15.3 ± 0.1^{b}	17.1 ± 1.7^{ab}	13.5 ± 0.3^{c}	27.7 ± 1.6^{d}	15.2 ± 0.7^{b}	18.5 ± 0.5^{a}
Phosphorus(g/kg)	2.1 ± 0.1^{a}	1.9 ± 0.1^{a}	2.4 ± 0.2^{a}	2.8 ± 0.1^{a}	3.6 ± 0.2^{b}	2.9 ± 0.1^{a}	2.8 ± 0.1^{a}
Potassium(g/kg)	28.1 ± 0.2^{a}	25.1 ± 0.1^{a}	28.3 ± 1.0^{a}	26.1 ± 0.1^{a}	34.5 ± 0.9^{b}	27.2 ± 0.3^{a}	28.7 ± 0.4^{a}
Sodium(mg/kg)	…6.1 ± 0.3^{a}	…6.0 ± 0.1^{a}	…6.1 ± 0.2^{a}	…5.8 ± 0.3^{ab}	…5.8 ± 0.1^{ab}	…5.4 ± 0.1^{ab}	…5.5 ± 0.1^{ab}

	Treatment						
Element	PFP*	HRAP*	CW*	NS*	Water*	F/H	P
Chloride(g/kg)	2.4 ± 0.4	1.0 ± 0.1	1.2 ± 0.1	1.3 ± 0.1	2.2 ± 0.2	F = 2.07	0.1041
Nitrogen(g/kg)	14.1 ± 0.1^{bc}	14.4 ± 0.1^{bc}	15.4 ± 0.1^{b}	30.1 ± 1.3^{d}	13.8 ± 0.1^{bc}	H = 32.18	0.0007
Phosphorus(g/kg)	2.5 ± 0.1^{a}	2.4 ± 0.1^{a}	2.1 ± 0.1^{a}	3.9 ± 0.2^{b}	2.7 ± 0.1^{a}	H = 33.29	0.0005
Potassium(g/kg)	25.7 ± 0.1^{a}	26.0 ± 0.1^{a}	25.9 ± 0.2^{a}	36.5 ± 1.1^{b}	26.8 ± 0.2^{a}	H = 33.10	0.0005
Sodium(mg/kg)	…5.6 ± 0.1^{ab}	…5.4 ± 0.2^{ab}	…5.4 ± 0.2^{ab}	…5.7 ± 0.2^{ab}	…5.0 ± 0.1^{b}	F = 0.85	0.5302

Anaerobic digestion (AD), primary-facultative-pond (PFP), high-rate-algal-pond (HRAP), constructed-wetland (CW), nutrient-solution (NS). Treatments marked with * were subject pH adjustment.

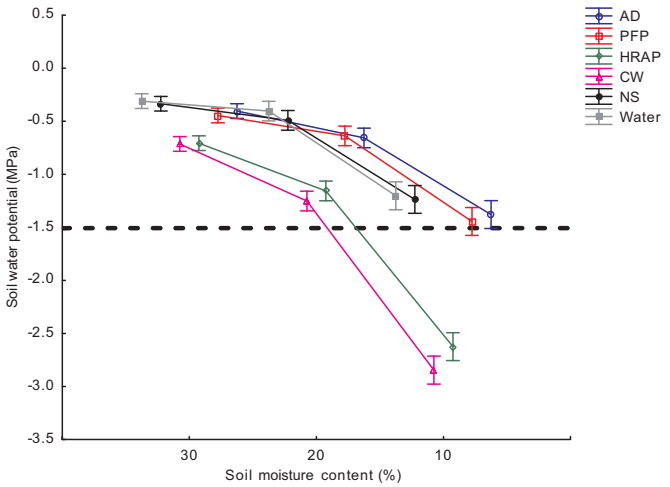

Fig. 5. The mean (± 95% confidence interval) water potential of soil irrigated under the different irrigation treatments: anaerobic digestion (AD), primary-facultative-pond (PFP), high-rate-algal-pond (HRAP), constructed-wetland (CW), nutrient-solution (NS) and water (Multifactor repeated measures ANOVA $F_{(10,\ 72)} = 45.64$, $p < 0.0001$). The dashed black line represents permanent wilting point; cabbages cannot access water from the soil below this line.

There was no difference in the air filled porosity and moisture concentration between soils subject the treatments (Multifactor-ANOVA, $p > 0.05$; Table 4).

3.5. Soil chemical characteristics

Brewery effluent treatments increased the pH, conductivity and sodium concentration of the soil while NS and water treatments did not (Table 5). Soils irrigated with BE treatments had a higher pH (9.49 ± 0.07) than soils irrigated with NS or water (8.49 ± 0.06) treatments. The conductivity of the soil was not influenced by an interaction between pH regime and treatment (Multifactor-ANOVA, $F_{(5108)} = 2.05$, $p = 0.08$; Table 5). Water source significantly affected the conductivity of the soil where soils subject to HRAP and CW treatments had the highest conductivity, followed by soils irrigated with AD and PFP BE (Multifactor-ANOVA, $F = 131.92$, $p < 0.0001$). Soils irrigated with NS and water had the lowest conductivity with a combined mean of 1025.86 ± 50.11 μs/cm^2 (Table 5). Soils subject to BE treatments had significantly higher concentrations of sodium (3919 ± 94.77 mg/kg) than soils irrigated with NS or water (920.58 ± 27.46 mg/kg, Kruskal-Wallis, $H_{(11,36)} = 32.62$, $p = 0.0006$; Table 5). After 12 weeks of irrigation, soils subject to BE treatments had a significantly higher SAR (8.18 ± 0.17) than soils irrigated with NS or water (2.20 ± 0.05, Kruskal-Wallis, $H_{(11,36)} = 33.25$, $p = 0.0005$; Table 5). The CEC and carbon concentration of the soil did not change during the trial and no difference was observed between soils subject to the different irrigation treatments (Multifactor ANOVA/Kruskal Wallis, $p > 0.05$; Table 5).

3.6. Soil biological characteristics

No significant difference was observed in carbon source utilisation of soils subject to the experimental treatments (Kruskal-Wallis, $p > 0.05$). On average soils contained 36.02% carbohydrate, 19.31% carboxylic and acetic acid, 22.11% amino acid, 18.45% polymer and 4.09% amine utilising bacteria (Fig. 6). The interaction between pH regime and water source had no influence on all the recorded soil biological indices (Multifactor-ANOVA, $P > 0.05$). No difference was observed for all soil biological indices recorded between pH adjusted and pH unadjusted treatments (Multifactor-ANOVA, $p > 0.05$). Therefore, the data presented in Table 6 represents combined pH adjusted and pH unadjusted treatments. The AWCD was significantly higher for soils irrigated with AD, PFP and HRAP treatments than soil irrigated with CW and NS treatments (ANOVA $F_{(5,24)} = 11.21$, $p < 0.0001$; Table 6). Soils irrigated with water had significantly lower AWCD, colony forming units, Shannon-Weaver index and richness compared with soils subjected to the other treatments (ANOVA, $P < 0.05$; Table 6). Soils subject to AD, PFP, HRAP, CW and NS treatments had similar colony forming units, Shannon-Weaver index and richness (Table 6).

4. Discussion

4.1. Plant growth and health

Each treatment contained different concentrations of plant nutrients, which should have affected the growth and health of plants they were used to irrigate. Cabbages irrigated with NS, AD and PFP treatments were significantly bigger than plants irrigated with HRAP, CW and water treatments. Cabbages irrigated with AD and PFP effluents where 12% heavier than cabbages irrigated with tap water. In order to sustain vigorous and healthy growth plants require sufficient concentrations of macro-and micro-nutrients [10,24].

Table 4
The mean (± standard error) starting and final physical characteristics of soils subject to the different irrigation treatments. Means in the same row with a different superscript are significantly different (Multifactor-ANOVA, $P < 0.05$). Values from the starting column were not included in the statistical analysis.

		Treatment						
Property	Start	AD	PFP	HRAP	CW	NS	Water	AD*
MWD(mm)	1.48 ± 0.03	1.48 ± 0.01^{a}	1.17 ± 0.04^{b}	1.21 ± 0.05^{b}	1.24 ± 0.05^{b}	1.45 ± 0.03^{a}	1.49 ± 0.05^{a}	1.45 ± 0.03^{a}
Infiltration.(cm/min)	2.13 ± 0.14	2.15 ± 0.26^{a}	1.95 ± 0.23^{a}	1.02 ± 0.15^{b}	0.94 ± 0.19^{b}	2.37 ± 0.26^{a}	0.47 ± 0.05^{b}	1.38 ± 0.25^{a}
Air filled porosity(%)	13.45 ± 0.19	8.53 ± 0.24	8.31 ± 0.27	7.60 ± 0.17	8.34 ± 0.22	7.77 ± 0.48	7.70 ± 0.29	7.71 ± 0.34
Moisture content(%)	27.31 ± 0.93	27.78 ± 0.85	29.21 ± 1.20	30.82 ± 0.81	30.95 ± 1.04	28.18 ± 1.26	32.27 ± 1.18	30.96 ± 0.53

	Treatment						
Property	PFP*	HRAP*	CW*	NS*	Water*	$F_{(5108)}$	P
MWD(mm)	1.22 ± 0.03^{b}	1.27 ± 0.01^{b}	1.24 ± 0.03^{b}	1.50 ± 0.03^{a}	1.44 ± 0.06^{a}	1.28	0.29
Infiltration.(cm/min)	1.60 ± 0.11^{a}	0.79 ± 0.10^{b}	0.84 ± 0.24^{b}	1.80 ± 0.16^{a}	0.68 ± 0.07^{b}	4.10	0.0019
Air filled porosity(%)	7.87 ± 0.43	7.80 ± 0.39	8.13 ± 0.55	7.97 ± 0.26	7.35 ± 0.56	0.56	0.7283
Moisture content(%)	31.37 ± 1.03	29.69 ± 0.71	61.54 ± 1.03	29.52 ± 1.17	29.86 ± 1.03	2.12	0.0679

Treatments marked with * were subject to pH adjustment. Anaerobic digestion (AD), primary-facultative-pond (PFP), high-rate-algal-pond (HRAP), constructed-wetland (CW), nutrient-solution (NS), mean weight diameter (MWD).

Table 5
The mean (± standard error) chemical characteristics of soils subject to the different irrigation treatments. Means in the same row with a different superscript are significantly different (Multifactor-ANOVA/Kruskal-Wallis, $P < 0.05$).

Element	AD	PFP	HRAP	CW	NS	Water	AD*
pH	9.55 ± .020	9.21 ± 0.22	9.79 ± 0.03	9.85 ± 0.04	8.55 ± 0.06	8.60 ± 0.06	9.30 ± 0.03
Carbon (g/kg)	7.23 ± 0.10	7.10 ± 0.15	6.83 ± 0.10	6.70 ± 0.21	7.13 ± 0.17	6.93 ± 0.20	7.17 ± 0.19
Conductivity(μs/cm^2)	1484.60 ± …62.86^a	1535.60 ± …66.20^a	2037.00 ± …42.95^b	2145.40 ± …71.72^b	1049.20 ± …70.47^c	0.982.80 ± …71.77^c	1663.40 ± …56.10 ^{a}
CEC…….(cmol(+)/kg)	…15.55 ± 2.76	…15.36 ± 1.23	…16.36 ± ….2.31	…15.46 ± ….2 0.50	…14.14 ± …1.08	…14.39 ± ….0.47	…13.13 ± ….0.94
Chloride……(mg/kg)	…315.23 ± 11.60^a	…205.71 ± ….57.36^b	…180.15 ± ….10.61^b	…447.94 ± ….9.96^c	…176.55 ± ….10.38^b	…362.60 ± ….27.19^c	…139.98 ± ….15.54^b
Sodium……(mg/Kg)	3797.67 ± 102.89^a	3712.67 ± …72.12^a	3967.00 ± …166.00^a	4334.67 ± …107.64^a	…813.00 ± ……4.93^b	…947.67 ± ….12.47^b	3423.00 ± …140.53^a
SAR	8.59 ± 0.17 ^{a}	8.44 ± 0.13 ^{a}	8.97 ± 0.25 ^{a}	9.56 ± 0.38 ^{a}	1.81 ± 0.13 ^{b}	2.16 ± 0.13 ^{b}	7.61 ± 0.20 ^{a}

Element	PFP*	HRAP*	CW*	NS*	Water*	F/H	P
pH	9.37 ± 0.05	9.48 ± 0.04	9.52 ± 0.05	8.41 ± 0.03	8.46 ± 0.03		
Carbon (g/kg)	6.97 ± 0.23	7.56 ± 0.13	6.90 ± 0.17	7.37 ± 0.13	7.10 ± 0.28	F = 1.36	0.2758
Conductivity(μs/cm^2)	1824.40 ± …65.88^{ab}	2026.60 ± …46.51^b	2258.60 ± …85.07^b	1074.40 ± …31.66^c	949.30 ± …44.98^c	F = 2.05	0.0774
CEC…….(cmol(+)/kg)	…17.14 ± ….0.89	…16.89 ± ….1.92	…13.45 ± ….1.12	…15.36 ± ….0.79	…14.16 ± ….1.02	H = 17.47	0.0948
Chloride……(mg/kg)	…304.27 ± ….9.46^a	…261.70 ± ….14.35^a	…324.90 ± ….10.54^a	…192.32 ± 21.64^b	…325.00 ± …….9.13^a	H = 31.44	0.0009
Sodium……(mg/Kg)	3764.33 ± ….56.70^a	4099.67 ± ….79.39^a	4675.00 ± ….46.52^a	…853.67 ± ….21.18^b	1374.00 ± ….71.24^b	H = 32.62	0.0006
SAR	8.66 ± 0.09 ^{a}	9.27 ± 0.20 ^{a}	10.55 ± 0.20 ^{c}	1.89 ± 0.08 ^{b}	2.98 ± 0.08 ^{b}	H = 33.25	0.0005

Treatments marked with * were subject to pH adjustment. Sodium adsorption ratio (SAR), anaerobic digestion (AD), primary-facultative-pond (PFP), high-rate-algal-pond (HRAP), constructed-wetland (CW), nutrient-solution (NS).

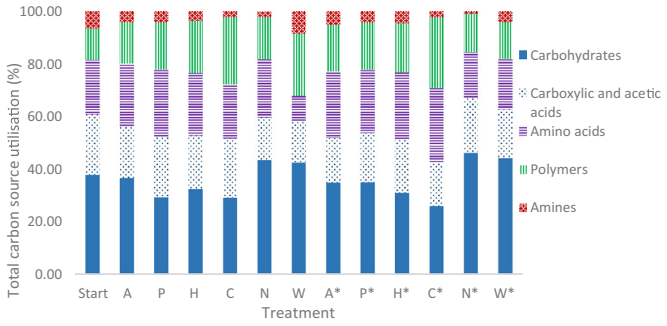

Fig. 6. The mean percent of carbon source utilisation of soil irrigated under the different irrigation treatments after 12 weeks. Treatments marked with * were subject to pH adjustment. Anaerobic digestion (A), primary-facultative-pond (P), high-rate-algal-pond (H), constructed-wetland (C), nutrient-solution (N) and water (W).

The HRAP and CW treatment processes utilise algae and plants which decrease the concentration of nutrients in the effluent as it is utilised to support plant growth. This is probably the main reason why plants irrigated with HRAP and CW treatment water were significantly smaller than plants irrigated with NS, AD and PFP treatments. To further support this conclusion, plants subject to HRAP and CW treatments showed signs of nutrient deficiency. Their outer leaves were yellow-orange and/or dark red purple in colour, which is known as chlorosis and necrosis, and is a sign of nitrogen, phosphorus and potassium deficiency [10]. Effluent treatment processes that remove plant nutrients are counterproductive when using effluents as an irrigation source for plants because they remove valuable nutrients that are needed to support plant growth. Anaerobically digested and post-PFP BE can be used to increase the yield of crops which are irrigated with water containing low concentrations of nutrients such as tap water or post-CW effluent.

Brewery effluent is not an ideal plant nutrient-solution and has certain characteristics that could inhibit plant growth. Anaerobically digested and post-PFP BE contained slightly higher concentrations of nitrogen and phosphorus than the NS. However, cabbages that were irrigated with BE subjected to AD and PFP were smaller than cabbages irrigated with NS, but showed no signs of nutrient deficiency. Therefore, certain characteristics of BE either inhibit the uptake of nutrients by cabbages or put stress on the plants resulting in less energy being spent on growth. It has previously been identified that the high conductivity, sodicity and pH in BE may decrease the growth and health of plants [3,30,32].

The pH of nutrient-solution plays a major role in the availability of macro-and micro-nutrients to plants, with the optimal range for most plants being between five and seven (Lucas & Davies 1961, [10]). The unadjusted BE treatments had pH values around 8.14 with HRAP treatment having a mean pH of 9.17 (Fig. 2). Surprisingly, no difference was observed in the growth, CCI and chemical composition of cabbages subject to BE treatments with or without pH adjustment. The pH range for good quality irrigation water is between 6.5 and 7.5 [10]. High pH values above 8.5 can cause the precipitation of Fe^{2+}, Mn^{2+}, PO_4, Ca^{2+} and Mn^{2+} to insoluble and plant unavailable salts [37,5]. However there was no difference in the growth, CCI or chemical composition of cabbages treated with pH unadjusted HRAP effluent (pH 9.17) and pH adjusted HRAP effluent (pH 6.5). Soils have the ability of resist pH changes, which is known as their buffering capacity (Buckman & Brady 1967). The buffering capacity could have counteracted the pH adjustment of BE.

The salinity of irrigation water is one of the concerns when using effluents as irrigation waters since salinity causes decreased growth and yield of most crops [26,33]. The mean EC of BE was 3301.85 μs/cm^2, which should reduce cabbage crops yields by 10–20% [9]. The mean mass of cabbages irrigated with AD and PFP effluents was 13% lower than cabbages irrigated with NS treatments. The high EC of AD and PFP treatments probably caused the decreased yield of cabbages when compared with NS irrigated cabbages because AD and PFP treatments contained higher concentrations of N and P than the NS treatment. Medium salinity of irrigation water (2000–3000 μs/cm^2) causes a decrease in yield in cabbages and most vegetables [33]. This is primarily due to the osmotic effects by decreasing the osmotic potential between the root plasma and soil water [13,25]. The severity of the crop response to salinity is species specific and is also mediated by environmental factors such as humidity, temperature, wind, light and air pollution [33]. It is important to select salt tolerant crops when using moderately saline effluents in irrigation.

4.2. Soil fertility

Soil water potential quantifies the tendency of water to move from one area to another area and is mainly affected by the concentration of salts in the soil [38,5]. It provides a measure of how easily soil water will move into the root of a plant. Soils subject to irrigation with HRAP and CW had significantly lower water potentials at all soil moisture concentrations than soils subjected to the other treatments. As the salinity of the irrigation water and/or soil increases, the water potential will decrease [4,5]. This means that plants have to spend more energy to get water from the soil, which in turn will compromise the growth of the plant [4,5]. The high salinity of BE probably increased the energy that plants invested in obtaining water, and this is a possible cause for the decreased growth of plants in these treatments. Most plants (including cabbages) cannot access water in the soil when the water potential decreases below − 1.5 MPa; this is represented by the dashed black line in Fig. 6.6 [19,6]. This means that in soils irrigated with HRAP and CW treated BE, plants could not access water in the soil when the gravimetric soil moisture concentration dropped below 15%. With the other treatments, plants could not access soil water when the gravimetric soil moisture concentration dropped below 10%. The negative affect of saline irrigation waters on the availability of water to plants demonstrated that the treatment process that

Table 6
The mean (± standard error) biological characteristics of soils subject to the different irrigation treatments. Means in the same row with a different superscript are significantly different (ANOVA, $P < 0.05$). Values in the start column were not included in the statistical analysis.

	Treatment			
	Start	AD	PFP	HRAP
Average well colour development	1.74 ± 0.22	1.61 ± 0.08[a]	1.81 ± 0.19[a]	1.75 ± 0.15[a]
Shannon-Weaver index	3.97 ± 0.34	3.85 ± 0.24[a]	3.65 ± 0.11[a]	3.82 ± 0.25[a]
Richness	57.33 ± 3.17	56.33 ± 2.08[a]	53.50 ± 2.81[a]	55.50 ± 2.28[a]
Colony forming units/gram soil	$7.94 \times 10^5 \pm 2.15 \times 10^4$	$7.78 \times 10^5 \pm 2.73 \times 10^{4a}$	$8.17 \times 10^5 \pm 2.94 \times 10^{4a}$	$5.83 \times 10^5 \pm 2.77 \times 10^{4a}$

	Treatment				
	CW	NS	Water	F	P
Average well colour development	1.21 ± 0.21[b]	1.08 ± 0.22[b]	0.38 ± 0.09[c]	11.21	< 0.0001
Shannon-Weaver index	2.94 ± 0.36[a]	3.75 ± 0.08[a]	2.37 ± 0.50[b]	5.72	0.0013
Richness	27.67 ± 7.00[b]	50.67 ± 3.56[a]	18.33 ± 5.42[b]	16.87	< 0.0001
Colony forming units/gram soil	$5.22 \times 10^5 \pm 2.64 \times 10^{4a}$	$4.98 \times 10^5 \pm 5.11 \times 10^{4a}$	$2.95 \times 10^5 \pm 2.31 \times 10^{4b}$	16.35	< 0.0001

Anaerobic digestion (AD), primary-facultative-pond (PFP), high-rate-algal-pond (HRAP), constructed-wetland (CW), nutrient-solution (NS).

results in BE having the lowest salinity would be the most suitable for crop irrigation.

The salinity of the treatments had an effect on the salinity and SAR of the soils, which in turn could affect the physical characteristics of the soil. At the beginning of the trial the soils had an SAR of 2.21 ± 0.05. After 12 weeks of irrigation, the soil SAR subject to BE treatments rose to 8.18 ± 0.17 while the SAR of soils subject NS and water remained the same throughout the trial. Soils that have a SAR > 13 are classified as sodic and are unsuitable for cultivating most vegetable crops ([36], Qadir & Schubert 2002). In most studies conducted on the use of wastewaters as an irrigation water source the SAR of the receiving soil has increased [16–18]. Dakoure et al. [8] irrigated eggplants grown on ferralsol soil with BE that had been treated using stabilisation ponds. After two seasons of irrigation they found that the effluent caused an increase in the SAR (2.9–20.3) and ESP of the soil accompanied by a strong degradation of hydro-structural soil properties. Soil irrigated with effluent had a decreased soil structural porosity, an increased bulk density and pH when compared with soils irrigated with tap water [8]. During this study the increase in SAR of the soil did not seem to negatively affect the physical structure of the soil with the exception of the stability of soil aggregates, which was slightly lower than soils irrigated the NS treatment. However, this trial was only run for 12 weeks and after prolonged irrigation with BE an increase in the SAR of the soil and accompanied decrease in the soil's physical structure would be expected. This emphasises the point that the BE treatment which results in the lowest sodium, chloride and salinity concentration will be most suitable for irrigation.

The different treatments influenced the infiltration rates of the soil, with soils subject to HRAP, CW and water treatments developing reduced infiltration rates. These treatments either had the highest sodium concentration (HRAP & CW) or the lowest conductivity (water). A high sodium concentration in irrigation water causes extreme flocculation, resulting in the formation of a soil crust and decreased infiltration rates while the low conductivity (< 500 $\mu S/cm^2$) of the water treatments caused soil particle dispersion resulting in a decreased soil structure and infiltration rates [2,5].

It is important to understand whether the application of BE onto soils will affect the community of microbes in the soil and thus the functions they provide [1]. No significant difference was observed in the carbon source utilisation of soils subject to the irrigation treatments (Fig. 9). Soils were dominated by carbohydrate (36.03%) utilising bacteria followed by amino acid (22.11%), carboxylic and acetic acid (19.31%), and polymer (18.45%) utilising bacteria. The literature shows both detrimental and enhancing effects of effluent on soil microbial population and communities, illustrating the complexity of relationships among soil microbial communities in agricultural soils [34,35]. From this study it can be concluded that the application of BE to agricultural soils does not affect the overall functioning and processes performed by the soil microbe community, in the short term. It may have changed the species composition of soil microbes but the overall metabolic community structure of microbes present was not affected. Future studies should investigate the changes in species composition of soil microbes using metagenomics and conduct the study over a longer timescale.

Soils subject to BE and NS treatments had significantly higher colony forming units per gram of soil than soils irrigated with tap water. To add to this the AWCD of the Biolog plates inoculated with soil subjected BE treatments was significantly higher those inoculated with soil irrigated with tap water. The same results were observed when looking at the diversity and richness of the Biolog plates. In previous studies the application of treated effluents onto soil had no effect or increased the microbial population in the soil ([31],[32]). These authors concluded that the increase in microbial populations could have been due to the increase in soil carbon. However, the increase in microbial populations could be due to the addition of microbes present in the wastewater [31]. Juwarkar & Dutta [15] and Kaushik et al. [16] observed a 50% reduction in soil microbial populations treated with raw distillery effluent.

In conclusion, the application of BE had no effect on the soil microbial populations in terms of numbers and metabolic diversity. However, the prolonged use of BE will result in a build-up of salt in the soil, which may have negative effects on soil microbial populations [7,8], as well as shift in diversity to more salt tolerant species [27,28].

4.3. Conclusion

Brewery effluent can be used as an irrigation water source for cabbage production and contains sufficient nutrients to improve crop growth, since cabbages irrigated with BE grew significantly larger than those irrigated with water-only. Post-AD or post-PFP BE is the most suitable for crop irrigation because it contains the highest concentration of plant nutrients and the lowest conductivity. However, BE is an inferior irrigation water source when compared with a nutritional irrigation water source. The pH adjustment of BE did not improve plant growth or the biological activity, chemical and physical fertility of the soil. Post-HRAP and CW BE were the least suitable for crop irrigation due to the lowest concentration of nutrients and the highest concentration of salts. The sodium and chloride concentrations, and overall conductivity are the biggest concerns when using BE because the combination results in an increase in the SAR and conductivity of the soil, which puts osmotic stress on the plants, resulting in reduced growth. The application of post-AD and post-PFP BE did not significantly decrease the biological and physical factors of the soil. However, after prolonged use it may negatively affect the soil's physical structure and reduce the soil's biological activity due to the sodium and chloride present in the effluent. Future studies should investigate the long term effects of irrigating soils with post-AD or post-PFP BE and alternative treatments of BE to eliminate Na and Cl ions should be developed.

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Volume 25, Issue , June 2021, Page

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Erratum regarding missing Declaration of Competing Interest statements in previously published articles

Declaration of Competing Interest statements were not included in the published version of the following articles that appeared in previous issues of «Water Resources and Industry»

The appropriate Declaration/Competing Interest statements, provided by the Authors, are included below.

1. "Adsorptive removal of cesium from aqueous solution using oxidized bamboo charcoal" [Water Resources and Industry, 2018; 19C: 35–46] 10.1016/j.wri.2018.01.001

   Declaration of competing interest: The Authors have no interests to declare.

2. "The potential use of treated brewery effluent as a water and nutrient source in irrigated crop production" [Water Resources and Industry, 2018; 19C: 47–60] 10.1016/j.wri.2018.02.001

   Declaration of competing interest: The Authors have no interests to declare.

3. "Reclamation of water and the synthesis of gypsum and limestone from acid mine drainage treatment process using a combination of pre-treated magnesite nanosheets, lime and CO2 bubbling" [Water Resources and Industry, 2018; 20C: 1–14] 10.1016/j.wri.2018.07.001

   Declaration of competing interest: The Authors have no interests to declare.

4. "Amorphous silica waste from a geothermal central as an adsorption agent of heavy metal ions for the regeneration of industrial pre-treated wastewater" [Water Resources and Industry, 2018; 20C: 15–22] 10.1016/j.wri.2018.07.002

   Declaration of competing interest: The Authors have no interests to declare.

5. "Performance Investigation of Atmospheric Water Harvesting Systems" [Water Resources and Industry, 2018; 20C: 23–28] 10.1016/j.wri.2018.08.001

   Declaration of competing interest: The Authors have no interests to declare.

6. "Incidence of dairy wastewater on morphological and physiological comportment of chemlali and chetoui olive" [Water Resources and Industry, 2018; 20C: 29–36] 10.1016/j.wri.2018.08.002

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7. "In-Plant Real-Time Manufacturing Water Content Characterisation" [Water Resources and Industry, 2018; 20C: 37–45] 10.1016/j.wri.2018.08.003

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8. "Development of iron oxide/activated carbon nanoparticle composite for the removal of Cr(VI), Cu(II) and Cd(II) ions from aqueous solution" [Water Resources and Industry, 2018; 20C: 54–74] 10.1016/j.wri.2018.10.001

   Declaration of competing interest: The Authors have no interests to declare.

9. "Assessment of the capability of an optical sensor for in-line real-time wastewater quality analysis in food manufacturing" [Water Resources and Industry, 2018; 20C: 75–81] 10.1016/j.wri.2018.10.002

   Declaration of competing interest: The Authors have no interests to declare.

10. "Modified amorphous silica from a geothermal central as a metal adsorption agent for the regeneration of wastewater" [Water Resources and Industry, 2018; 20C: 100105] 10.1016/j.wri.2018.100105

    Declaration of competing interest: The Authors have no interests to declare.

11. "Pilot-scale evaluation of bio-decolorization and biodegradation of reactive textile wastewater: An impact on its use in irrigation of wheat crop" [Water Resources and Industry, 2019; 21C: 100106] 10.1016/j.wri.2019.100106

    Declaration of competing interest: The Authors have no interests to declare.

12. "Titania coated silica nanocomposite prepared via encapsulation method for the degradation of Safranin-O dye from aqueous solution: Optimization using statistical design" [Water Resources and Industry, 2019; 22C: 100071] 10.1016/j.wri.2016.08.001

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