Article

Journal of the Brazilian Chemical Society

https://dx.doi.org/10.21577/0103-5053.20230085

J. Braz. Chem. Soc. **2024**, *35*, 1, e-20230085, 1-9

Anaerobically Treated Leachate from a Composting Plant: Characterization and Evaluation as a Biofertilizer

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Leachate from a composting plant was characterized and applied as a biofertilizer in lettuce crops. Characteristics of untreated (UE) and anaerobically treated (TE) leachate samples were compared. The pH of TE (8.2) increased in relation to the UE (5.2) due to an increase in ammonia nitrogen in TE (1197 mg L^{-1}) compared to UE (859 mg L^{-1}). Anaerobic treatment was efficient in the removal of organic matter from the leachate, evaluated by the decrease of dissolved organic carbon, biochemical oxygen demand, total organic carbon and total solids. K presented the highest concentration (1743 mg L^{-1}) in TE, followed by Mg (135 mg L^{-1}). Cd, Pb and Cr were present at low concentrations in the samples, 0.047, 0.206 and 0.081 mg L^{-1}, respectively. *Salmonella*, thermotolerant coliforms and viable helminth eggs were not present in TE, which was applied as a biofertilizer in a lettuce crop and compared to mineral fertilization based on fresh matter and dry matter production. Lettuce production using TE was statistically equivalent to mineral fertilization. Toxic metals were not detected in the lettuce shoots. It was concluded that the anaerobically treated leachate from the composting company has the potential to be used as a biofertilizer.

Keywords: sustainability, organic solid waste treatment, food waste, fertilizers, lettuce (*Lactuca sativa*)

Introduction

Large and increasing quantities of organic solid wastes are generated due to population growth and rapid urbanization. Thus, it is necessary to find sustainable treatment processes, aimed at minimizing the destination of these wastes to landfills, which occupy large areas and release greenhouse gases.[1,2] More than 50% of the waste produced in homes is organic and can be recycled and reused.[3] Anaerobic digestion and composting processes can be used as recycling alternatives, with the latter more viable because it is more economical and produces a stable compost.[1]

Composting is the aerobic microbial stabilization of organic matter.[4] In this process, microbiological transformations and chemical reactions occur, including hydrolysis, proteolysis, ammonification, nitrification, carbon mineralization and humification. Organic waste is transformed forming a stabilized product called compost, which can be used as a soil fertilizer.[5] The compost or organic fertilizer allows nutrients to return to the soil, improving its physical, chemical, and biological conditions, reducing the need for chemical fertilizers. Thus, recycling organic waste through composting is considered an environmentally friendly technique that both reduces waste volumes sent to landfills and produces a nutrient-rich product.[6,7]

Despite these benefits, composting poses some environmental challenges.[8] Byproducts such as liquid effluent and odors can be formed during composting due to excess humidity, compaction and an imbalance between carbon and nitrogen in the organic wastes.[9] The effluent, known as leachate or slurry, is a black or brownish liquid

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Editor handled this article: Maria Cristina Canela (Associate)

with a strong odor and high contents of organic matter, inorganic salts, ammonia nitrogen and metal ions.[10]

Leachate originates from undesirable anaerobic degradation during composting and arises from three sources, (*i*) water inherent in the organic waste itself, (*ii*) water generated in biochemical reactions and (*iii*) rainwater or moisture content adjustment.[11] Leachate generation during composting is influenced by temperature and the amount of waste added to the windrows[12] and its characteristics vary depending on waste composition, climatic and hydrological conditions and how the process is conducted. Leachate contains a multitude of dissolved and suspended organic and inorganic compounds, in addition to pathogenic microorganisms[11] and its generation is a matter of concern for composting facilities because of its high biochemical and chemical oxygen demands and ammonia contents.[13]

Leachate can only be discharged into water bodies after undergoing treatment because of its high pollutant load. Several processes can be used for this purpose, including aerobic and anaerobic stabilization, flocculation, adsorption, membrane filtration and chemical precipitation.[14] However, because of the limitations in removal of different types of contaminants by different processes, the combination of physical, chemical and biological methods has been used to improve treatment efficiency,[15] although efficiency may still be limited and treatment costs may be too high to make them economically feasible at present.[16] Therefore, other ecologically and economically viable solutions must be sought for leachate treatment and disposal.[17]

The high nutrient contents typically found in composting leachates suggest their potential for application as fertilizers. Moreover, leachate recycling into a value-added product, biofertilizer, would be an economic benefit for composting companies.[18,19] However, caution is necessary, given the potential presence of toxic compounds which may affect plant production and/or lead to groundwater contamination.[12] Given the aforementioned, this work was undertaken to chemically characterize the anaerobic reactor effluent generated at a food waste composting plant and evaluate its potential as a biofertilizer in lettuce production (*Lactuca sativa*).

Experimental

Reagents and solutions

All reagents used in this work were of analytical grade and the solutions were prepared with type 1 water obtained by Milli-Q system (Millipore Corporation from Bedford, USA). Magnesium sulfate, silver sulfate, ferric chloride, mercury(II) sulfate, sodium sulfate, manganese sulfate and sodium azide were purchased from Vetec (Darmstadt, Germany). Hydrochloric acid, calcium chloride and glycerin were purchased from Afphatec (São José dos Pinhais, Brazil). Sulfuric acid, boric acid, nitric acid, stannous chloride, ammonium molybdate, potassium sulfate and silver sulfate were obtained from Neon (Suzano, Brazil). Potassium iodide and phenolphthalein were obtained from Fmaia (Belo Horizonte, Brazil). Potassium dichromate was purchased from Isofar (Duque de Caxias, Brazil). Potassium hydroxide, copper sulfate and soluble starch were obtained from Dinâmica (Itaiutaba, Brazil). Phosphorus pentoxide was purchased from Sigma-Aldrich (Saint Louis, USA).

Effluent collection

Leachate samples were collected at a food waste composting plant located in Betim, Minas Gerais, Brazil. The organic waste composting plant receives food waste from approximately 40 commercial establishments, including food distributors and restaurants, as well as pruning and garden waste. During this study (2019-2021), an average of 168 tons of organic waste were composted, 56 tons of compost were produced and 43 m^3 of leachate were generated *per* month (Figure S1, Supplementary Information (SI) section). The relatively large volume of leachate included wastewater from washing the drums used in the collection of food waste, the food waste's moisture content, rainfall, and the composting process itself.

At the plant, a new batch of compost is started every 30 days. The windrows (approximately 2 m × 10 m × 10 m) are assembled with wet (food) and dry (pruning) organic waste, at a 3:1 ratio (m/m). Composting is conducted by natural aeration in which the mechanized turning of the compost pile is carried out by means of a wheel loader, once a week, for the first and last 30 days of the composting process. Leachate, primarily generated during the initial stage of composting, is screened and sent to the anaerobic reactor, composed of three 30 m^3 tanks in series (the treatment process is illustrated in Figure S2, SI section).

Untreated (UE) samples were taken from the fiber box that stores leachate drained from the composting process before it is pumped to the anaerobic treatment tanks and anaerobically treated (TE) samples were collected after the third anaerobic treatment tank (Figure S2). Samples were collected in 1 L amber glass bottles, transported under refrigeration, and stored at 4 ºC until characterization. Four UE (Nov/2020 to Feb/2021) samples and twelve TE samples (Oct/2019 to Feb/2020 and Aug/2020 to Feb/2021) were collected in different months from 2019 to 2021. To carry out the biological assay using the TE as a biofertilizer in the lettuce crop, the TE was collected in August 2020 in a 25-liter polyethylene gallon, which was stored at room temperature for a period of 6 months. Monthly chemical analyses were performed for these samples.

Effluent characterization

The UE and TE samples were characterized according to standard methods[20] by quantifying pH (standard method: 4500-H^+ B), biochemical oxygen demand (BOD_5) (standard method: 5210 B), chemical oxygen demand (COD) (standard method: 5220 D), total organic carbon (TOC) (standard method: 5310 B); total solids (TS), total volatile solids (TSV), total fixed solids (TSF), total suspended solids (TSS), volatile suspended solids (VSS), fixed suspended solids (FSS) (standard method: 2540 B, C, D and E); total Kjeldahl (TKN) and ammonia nitrogen (N-NH_3) (standard methods: 4500-Norg B, 4500-NH_3 C) and phosphorous (P) (standard method: 4500-P D).

Samples pH was measured at the composting plant, immediately after collection (Kasvi K39-1014B electrode from São José do Pinhais, Brazil). Colorimetric analyses (COD and P) were performed by spectrophotometry (Hach, model DR3800 from CO, USA). Samples were digested in a digital thermoreactor (Hach, model DRB200 from CO, USA) for COD analyses. TOC analyses were performed in an automated total organic carbon analyzer (Shimadzu, model -VCSH from Kyoto, Japan).

The metals cadmium (Cd), calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn) and zinc (Zn) were quantified in TE samples by atomic absorption spectrophotometry (Agilent Technologies, model 240FS, from Santa Clara, USA), while potassium (K) was quantified by flame photometry (Micronal, model B462 from São Paulo, Brazil). Linear working ranges, limits of quantification and the wavelengths used for quantification of the metals analyzed are presented in Table S1 (SI section).

Thermotolerant coliforms, viable helminth eggs and *Salmonella* were quantified in TE samples collected in July and October, 2020, according to EPA Methods.[21,22]

Biofertilizer assay

A red-yellow latosol (LVA) of clayey texture, typical of the region of Viçosa, Minas Gerais, Brazil (20°46 ‘11.2”S 42°52 ‘09.3”W), was used in the biofertilizer assay. An appropriate mass of soil was collected at a depth between 0 and 20 cm, air-dried at room temperature, loosened, and screened through a 5 mm mesh sieve to remove coarse fragments, and then homogenized.

Lettuce seedlings (*Latuca sativa*) in the three to four leaf stage of development were purchased in Viçosa and transplanted to 3.6 L pots, filled with the screened soil amended with 7.6 mg of phosphorus pentoxide (18% P_2O_5). Lettuce was selected because it has a short production cycle.

TE doses were calculated based on potassium content. Doses of 0 mL (T1, negative control), 25 mL (T3), 50 mL (T4), 100 mL (T5), 150 mL (T6), 250 mL (T7), 350 mL (T8), 500 mL (T9) and 650 mL (T10) were used. Each dose was divided into five applications, with the final volume of each application completed to 150 mL with tap water, to ensure the same humidity in all soil pots. Mineral fertilizer (T2) used as the positive control contained 0.875 g of K_2O (60%) and 1.17 g of urea (45%) in 150 mL tap water. All treatments were performed in quadruplicate. A general experimental scheme is presented in Figure S3 (SI section).

The first (bio)fertilizer dose was applied three days after seedling transplant and the other four doses were applied every seven days thereafter. The pots were irrigated 4 times daily. Irrigation was interrupted approximately 24 h before (bio)fertilizer application and resumed 18 h afterwards. After the fourth application, irrigation was only reinitiated after 40 h due to rainy weather.

Lettuce plants were manually harvested 38 days after transplanting when the lettuce was well developed, by cutting them at soil level. Fresh (FM) and dry (DM) matter of the harvested plants (leaves) were determined. FM was obtained by weighing the harvested plant. To determine the DM, three leaves from the crown of each plant were selected, weighed, placed in paper bags, and dried in an oven at 70 °C for 72 h. Similarly, sized leaves were collected from all plants to ensure greater analytical accuracy. Oven-dried leaves were weighed to determine DM.

After harvesting, the quadruplicate soil samples from each treatment were homogenized, resulting in a single sample for each treatment. Metals contents (P, K, Ca, Mg, S, Cu, Zn, Mn, B, Ni, Pb, Cd and Cr) were determined in soil and DM samples. To this end, samples were digested with a mixture of nitric/perchloric acid and multielement analysis was performed using inductively coupled plasma optical emission spectrometry (PerkinElmer, Model Optima 8300 DV from Waltham, USA). Nitrogen was determined by Kjeldahl distillation.

Lettuce plant FM and DM results for the different treatments were tested for normality (Shapiro-Wilk test) and homogeneity of variances (Cochran and Bartlett’s test) and regression analysis was performed on DM and FM as a function of TE dose. The results were also submitted to analysis of variance, using the *F* test at a level of 5% significance. TE results were compared with mineral fertilizer results using Dunnett’s test, at a level of 5%

significance. All statistical analyses were performed using the R program v. 3.6.1.[23]

Results and Discussion

The temperature profile in a compost windrow over the first 30 days of composting is presented in Figure 1, where it is possible to observe that the maximum temperature recorded was 50 °C, with a duration of only one day.

During an on-site visit, it was found that composting windrows were excessively wide, with no specific geometric configuration, which likely contributed to the low temperature of short duration and leachate formation. Since improper geometry has detrimental effects on temperature, humidity, and aeration during composting.[24]

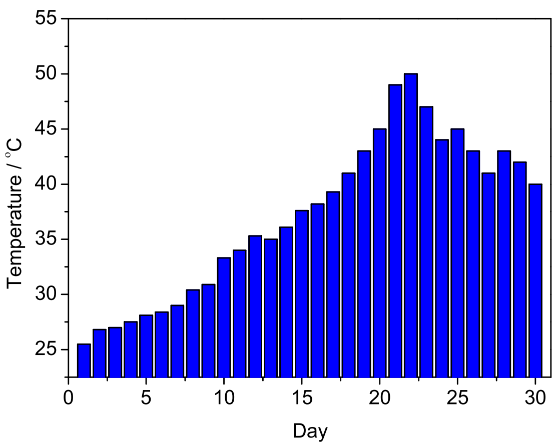

Figure 1. Temperature profile in a windrow over the first 30 days of composting.

Composting is an exothermic process and the desired temperature in the composting windrows can be reached by properly managing the humidity, the configuration of the windrows and the aeration rate, among other factors.[25] The greater the amount of composted residues, the higher the temperature, which should reach over 55 °C to guarantee the sanitation of the material through inactivation of pathogens and weed seeds.[26] However, excess moisture leads to slow degradation of organic matter and generation of effluents with the absence of the thermophilic phase.[24] Since composting is an aerobic oxidation process, in order to maintain microbiological activities, it is necessary to maintain oxygen in the windrows, which can be achieved with frequent turnings.[27]

Effluent characterization

Characteristics of the raw (UE) and treated (TE) leachate samples are presented in Figure 2 (detailed results are presented in Tables S2, S3, S4, SI section). UE characteristics were similar to those reported by Mirghorayshi *et al.*[28] for compost leachate collected at a municipal solid waste recycling plant.

TE characteristics remained fairly constant, except for the September sample, which presented high TOC, COD and P (Tables S3, S4) and an unusually dark color (Figure S4, SI section). The abrupt drop in treatment efficiency in September was traced back to the cleaning of the anaerobic tanks that month to remove excess sludge that had accumulated since the plant started operation in 2015. Average values of the parameters measured (excluded those in the abnormal September sample) were within the ranges cited in the literature for biologically treated leachates.[27-29]

Microbiological analyses (*Salmonella*, thermotolerant coliforms and viable helminth eggs) were performed on samples of treated effluent from July and October 2020, and all results were negative for the presence of these pathogens.

Untreated leachate samples presented a slightly acidic pH of 5.2, that increased to 8.2 after anaerobic treatment. Ammonification, the mineralization of organic nitrogen by bacteria, occurs at the beginning of composting, releasing NH_4^+ that increases the liquid phase pH.[5] The ammonification process was evidenced by the increase in ammonia in the TE compared to UE (Figure 2) and is commonly observed after of anaerobic treatment.[5] On the other hand, phosphorus decreased after anaerobic treatment, probably as a result of precipitation of phosphate salts in the anaerobic tanks.

The increase in pH after anaerobic treatment was also a result of the removal of volatile organic acids, which were converted to CO_2 and CH_4 during anaerobic degradation.[30] Anaerobic treatment proved very efficient in organic matter degradation, with removals of 95% or more of leachate COD, BOD, TOC and volatile solids.

K was the metal found in the highest concentration in all samples (Table 1), followed by Mg, Ca, Fe and Zn, all essential elements for plants. The high K levels and the same relative order of other essential elements have also been reported in other studies on composting plant effluents.[30,31]

In addition, according to the 396/2008 CONAMA resolution,[32] the concentration values of all elements in the TE, except Cd, are below the maxima allowed in groundwater used for irrigation: Cr 100 µg L^{-1}, Cu 200 µg L^{-1}, Mn 200 µg L^{-1}, Fe 5 mg L^{-1}, Cd 10 µg L^{-1}, Pb 5 mg L^{-1} and Zn 2 mg L^{-1}.

TE samples contained large quantities of potassium and ammonia nitrogen, essential plant macronutrients, indicating this effluent had potential value in fertilization. Thus, a bioassay was carried out to assess the use of TE as a biofertilizer in lettuce plants.

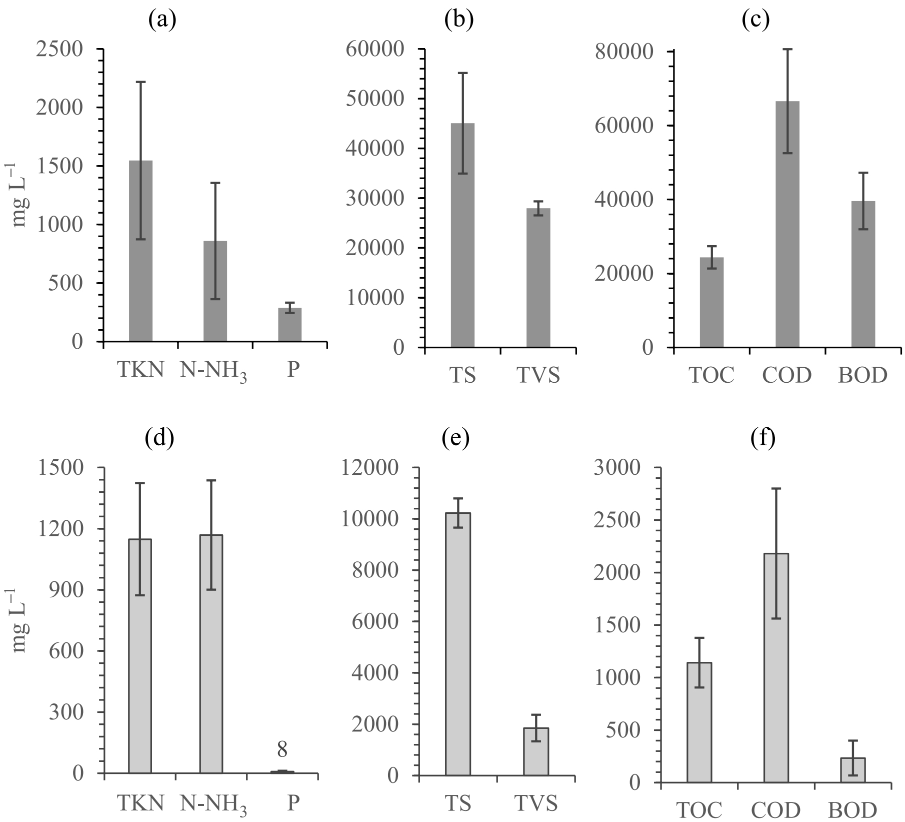

Figure 2. Characteristics of untreated effluent (a, b and c) and treated effluent (d, e and f). TKN = total Kjeldahl N; $N\text{-}NH_3$ = ammonia N; P = phosphorous; TS = total solids; TVS = total volatile solids; TOC = total organic carbon; COD = chemical oxygen demands; BOD = biochemical oxygen demands. Error bars represent standard deviations, n = 4 (a, b and c), n = 11 (d, e and f).

Table 1. Metal contents of the TE samples

Month/year	Cr / (mg L^{-1})	Cu / (mg L^{-1})	Mn / (mg L^{-1})	Fe / (mg L^{-1})	Cd / (mg L^{-1})	Pb / (mg L^{-1})	Zn / (mg L^{-1})	Ca / (mg L^{-1})	Mg / (mg L^{-1})	K / (mg L^{-1})
Nov/2019	< LOQ[a]	0.034	0.524	16.60	0.054	< LOQ[a]	0.300	25.00	201.0	1443
Dec/2019	0.062	0.029	0.135	13.10	0.042	0.103	0.140	22.00	358.0	950
Jan/2020	< LOQ[a]	0.088	0.083	10.60	0.021	< LOQ[a]	0.090	15.00	150.0	1546
Feb/2020	0.062	0.043	0.214	10.40	0.045	< LOQ[a]	0.280	30.00	144.0	1535
Aug/2020[b]	0.156	0.033	0.123	12.10	0.102	0.740	0.250	4.00	123.0	2007
Sep/2020	< LOQ[a]	0.460	3.446	63.00	0.020	< LOQ[a]	10.50	225.0	77.0	1682
Oct/2020	< LOQ[a]	0.068	0.063	5.50	0.020	0.099	1.36	6.00	95.0	1849
Nov/2020	0.065	0.110	0.046	7.60	0.063	0.094	0.430	1.00	1.0	1725
Dec/2020	0.060	0.072	0.058	5.40	< LOQ[a]	0.092	1.52	4.00	104.0	1633
Jan/2021	< LOQ[a]	0.074	0.039	3.90	0.027	0.113	0.520	6.00	100.0	1993
Feb/2021	< LOQ[a]	0.042	0.047	4.60	< LOQ[a]	0.202	0.150	15.00	71.0	2750
Average[c]	0.081	0.059	0.133	8.98	0.047	0.206	0.504	12.80	134.7	1743

[a]< LOQ: less than the limit of quantification; [b]the results for the month of August refer to the effluent used as biofertilizer; [c]the average was calculated excluding the values for the September sample.

Evaluation of treated effluent as biofertilizer for lettuce production

The TE sample collected in August/2020 was evaluated for use as a biofertilizer for lettuce production. Lettuce growth after 38 days is illustrated in Figure 3. Plants from treatments T1 and T3 through T6 presented yellowish, chlorotic old leaves, indicating a possible nitrogen deficiency. Plants from treatments T7 through T10 were more similar to those that received mineral fertilizer (T2), although the older leaves from T7 were greenish-yellow, while the older leaves from T8, T9 and T10 plants were greenish, with no evidence of nitrogen deficiency. Lack of nitrogen reduces plant growth and causes chlorosis in older leaves, which can even dry out if the deficiency is prolonged.[33,34] The decrease in productivity caused by lack of nitrogen is more evident in leafy vegetables, in which older leaves are uniformly yellowish because of the displacement of nitrogen from these to the newer leaves of the plant.[35]

Figure 3. Lettuce evolution over six weeks (38 days) treated with different volumes TE after transplanting. T1: 0 mL; T2: mineral fertilizer; T3: 25 mL; T4: 50 mL; T5:100 mL; T6: 150 mL; T7: 250 mL; T8: 350 mL; T9: 500 mL and T10: 650 mL.

Regression models of FM and DM of the aerial part of the plant as a function of the applied doses of treated effluent are presented in Figure 4. FM and DM production increased up to a dose of approximately 400 mL TE, and decreased at higher doses, indicating the plants were intoxicated at higher doses. According to the models, the highest yields would occur at doses of 374 and 381 mL for fresh and dry matter, respectively. Furthermore, biofertilization with doses of 250, 350 and 500 mL TE (T7, T8 and T9) resulted in fresh and dry matter production statistically equivalent to that of mineral fertilization (Table S5, SI section).

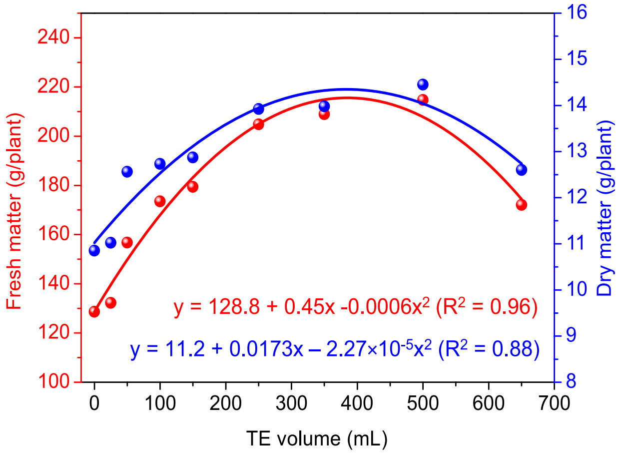

Figure 4. Fresh matter and dry matter production as a function of different treated effluent amounts. T1: 0 mL; T3: 25 mL; T4: 50 mL; T5:100 mL; T6: 150 mL; T7: 250 mL; T8: 350 mL; T9: 500 mL and T10: 650 mL.

Multi-element analysis of lettuce shoots

The levels of macronutrients P, Ca, Mg and S in the lettuce leaves remained unchanged with the increase in the TE dose (Table S6, SI section). However, there was an increase in N and K content as a function of the applied dose (Figure 5a). A decrease in K content occurred at doses of 650 mL or greater, indicating a possible poisoning of the plant, leading to a decrease in potassium absorption.

Nitrogen and potassium are two important plant macronutrients, and an adequate dose of these elements will result in increased growth and mass.[35] Nitrogen deficiency was found to result in a 78% decrease in the fresh and dry weights of lettuce grown in a greenhouse[36] and potassium deficiency has been shown to cause a reduction in lettuce yield and quality.[37] Lettuce leaf N and

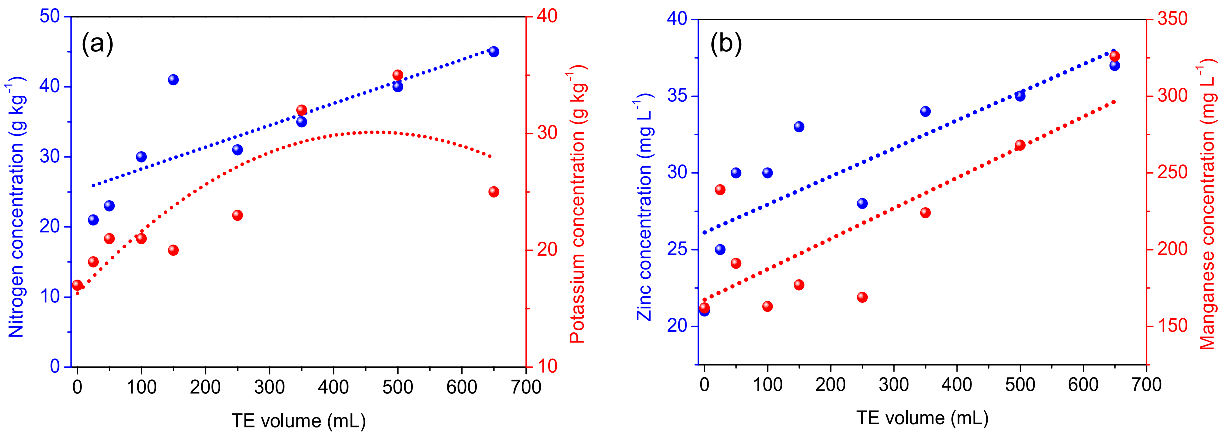

Figure 5. Elements content in the aerial part of lettuce as a function of the treatment effluent dose applied. (a) Nitrogen and potassium and (b) zinc and manganese.

K contents typically fall within the ranges of 30-50 and 50-80 g kg^{-1}, respectively.[38] This level of nitrogen was found in plants from treatments T2 (mineral fertilizer) and T5-T10, however no treatment, not even mineral fertilizer, reached contents of K within the range cited (Figure 5a).

Micronutrient and toxic metals contents in the lettuce leaves are presented in Table 2. While boron (B) content did not correlate with TE dose, the micronutrients Zn and Mn showed a tendency to increase with the TE dose (Figure 5b). Zinc participates in nitrogen metabolism and is required for the synthesis of the amino acid tryptophan[35] and Zn deficiency causes a decrease and distortion of lettuce leaves. Mn, the most abundant micronutrient in the lettuce leaves, plays a role in chlorophyll formation.[35] The toxic metals Ni and Pb were not detected in the lettuce shoots in any of the treatments. Cr was not detected in treatments T7, T8 and T9, but was found in lettuce from the other treatments, while Cd was found at a low level in all treatments.

According to the Brazilian resolution No. 42,[39] which establishes the maximum levels of inorganic contaminants permitted in food, the maximum value allowed for Cd in lettuce is 0.2 mg kg^{-1}. All treatments with TE were within the established maximum limit except T10. The presence of Cd in the lettuce leaves in all treatments TE may have originated from the phosphorus pentoxide (18% m/m of P_2O_5) added to the soil to supplement the low amount of P in the TE. It has been reported that one of the causes of the increase in the cadmium content in soil is the use of synthetic phosphate fertilizers that contain cadmium as an impurity.[40]

Residual metal content in the soil

After harvesting the lettuce, soil samples were collected for chemical analysis, the results of which are presented in Table 3. Soil pH varied between 5.3 and 6.1 for all treatments, close to the ideal range (6 to 7), at which there is the greatest availability of nutrients for plants and decreased availability of aluminum.[41] In strongly acidic soils (pH < 5), aluminum becomes toxic and impedes plant growth by restricting root growth, making it impossible to absorb essential nutrients. The rise in pH leads to aluminum precipitation, making it unavailable to plants and therefore not prejudicial to agricultural productivity.[41,42]

There was no significant change in the contents of Ca, Mg and Cu in the soil after treatments with TE, while K and Mn increased with the increase in TE dose (Table 3). The physicochemical stability of the TE used in the biofertilizer

Table 2. Content of micronutrients and toxic metals in lettuce

T[a]	Concentration / (mg L^{-1})							
	Cu	Zn	Mn	B	Ni	Pb	Cd	Cr
T1	3.0 ± 1.0	21.0 ± 10.0	162.0 ± 72.9	49.0 ± 17.0	ND[b]	ND	0.20 ± 0.05	0.10 ± 0.10
T2	6.0 ± 1.0	38.0 ± 4.4	293.0 ± 35.9	69.0 ± 7.8	ND	ND	0.20 ± 0.02	0.30 ± 0.04
T3	4.0 ± 0.3	25.0 ± 2.0	239.0 ± 59.6	60.0 ± 9.2	ND	ND	0.20 ± 0.10	0.10 ± 0.10
T4	5.0 ± 0.3	30.0 ± 5.4	191.0 ± 12.1	66.0 ± 14.0	ND	ND	0.20 ± 0.02	0.20 ± 0.10
T5	5.0 ± 0.6	30.0 ± 5.1	163.0 ± 52.9	67.0 ± 11.0	ND	ND	0.20 ± 0.10	0.10 ± 0.04
T6	6.0 ± 0.4	33.0 ± 3.4	177.0 ± 23.4	70.0 ± 13.0	ND	ND	0.20 ± 0.01	2.70 ± 3.50
T7	6.0 ± 0.8	28.0 ± 3.2	169.0 ± 22.2	57.0 ± 16.0	ND	ND	0.20 ± 0.04	ND
T8	6.0 ± 1.0	34.0 ± 6.9	224.0 ± 13.2	51.0 ± 5.5	ND	ND	0.20 ± 0.04	ND
T9	6.0 ± 0.9	35.0 ± 7.8	268.0 ± 91.8	61.0 ± 20.0	ND	ND	0.20 ± 0.05	ND
T10	7.0 ± 0.6	37.0 ± 5.2	326.0 ± 34.0	64.0 ± 8.9	ND	ND	0.30 ± 0.04	0.20

T[a]: treatment; ND: not detected.

Table 3. Soil pH values and residual metals contents after harvesting lettuce plants

Treatment	pH	Ca / (mg L^{-1})	Mg / (mg L^{-1})	Cu / (mg L^{-1})	K / (mg L^{-1})	Mn / (mg L^{-1})
T1[a]	5.7	2.4	0.59	3.8	22	75
T2[b]	5.3	2.3	0.48	3.7	87	78
T3	5.7	2.5	0.62	4.3	12	76
T4	5.7	2.7	0.61	4.0	14	71
T5	6.1	2.5	0.61	4.2	24	78
T6	5.7	2.0	0.55	4.6	32	105
T7	5.8	2.2	0.62	4.2	81	87
T8	5.7	2.2	0.67	4.4	158	91
T9	5.8	2.6	0.76	5.3	218	160
T10	5.5	2.3	0.72	4.7	313	167

[a]T1: negative control; [b]T2: mineral fertilizer (nitrogen and potassium).

assay was evaluated over the course of the 6 months of the experiment (Table S7, SI section) and TE composition proved stable over time. This stability was probably related to the reduced content of biodegradable substances and the presence of humic substances, which are more difficult to degrade.[11] In horticulture, these substances are considered biostimulants, since they are closely linked to the growth and development of plants, providing greater absorption of nutrients.[42] However, the use of fertilizers must be based on good agricultural practices, as the excessive use of nutrients can induce the phenomenon of eutrophication.

Conclusions

Anaerobically treated effluent from a food waste composting plant presented high concentrations of macro and micronutrients important for lettuce growth. Application of 250 to 500 mL of the treated effluent in lettuce seedlings was equivalent to mineral fertilization with nitrogen and potassium in terms of fresh and dry matter production. As a result, it can be concluded that the treated effluent has the potential to be used as a biofertilizer. Furthermore, since it is a waste product, with no production cost, its use is a way of adding value to this material, in a sustainable route for handling organic solid waste, minimizing possible environmental impacts of its disposal or discharge to the environment. However, it must be emphasized that more studies are important and necessary before to be include these residues as biofertilizers.

Supplementary Information

Supplementary information is available free of charge at http://jbcs.sbq.org.br as PDF file.

Acknowledgments

The authors would like to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG - APQ-01275-18), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001 and Employee Qualification Scholarship Program of the Federal Institute of Northern Minas Gerais (IFNMG).

Author Contributions

Rita de Cássia M. Freire was responsible for data curation, formal analysis, investigation, methodology, validation, writing original draft; Adalin Cezar M. de Aguiar for formal analysis, investigation, methodology, writing original draft; Mayra Aparecida Nascimento for conceptualization, supervision, writing-review and editing; Felipe S. O. Cruz for conceptualization, formal analysis, methodology, supervision, writing review and editing; Ann H. Mounteer for conceptualization, funding acquisition, supervision, writing review and editing; Antônio Alberto Silva for conceptualization, funding acquisition, writing review and editing; Renata P. Lopes for conceptualization, data curation, funding acquisition, project administration, supervision, writing review and editing.

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Submitted: February 1, 2023
Published online: May 30, 2023