Fertigation of *Brassica rapa* L. using treated landfill leachate as a nutrient recycling option

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Optimising nutrient availability and minimising plant metal contamination are vital in sustainable agriculture. This paper reports experiments in which treated leachate was used at different concentrations with predetermined N content for fertigation of *Brassica rapa* L. (leafy vegetable). An inorganic fertiliser, with N content equivalent to the leachate amount, was also prepared, as well as a control. Growth (leaf length, leaf width and stem height), harvest parameters (total number of leaves, root length and root dry weight) and specific growth rates (mm/day) were determined for three consecutive seasons. The dry weights of leaves, roots and stems in the leachate treatments were within the ranges of 1.95–3.60 g, 1.18–3.60 g and 0.33–1.37 g, with biomasses of 1.75 g, 1.14 g and 0.2 g, respectively, which were higher than those of the control. *B. rapa* L. fertigated with 25% diluted treated leachate recorded high specific growth rate and a leaf length of 0.53 mm/day and 0.23.17±0.58 cm, respectively (%N=0.023; $p<0.05$). The maximum permissible mineral concentration set by the Food and Agricultural Organization of the United Nations/World Health Organization (FAO/WHO) was compared with that of the grown plants. Treated leachate can increase plant nutrient content.

Introduction

Fertigation is the technique of supplying dissolved fertiliser to crops through irrigation systems. This approach can improve application efficiency and reduce the need to export fertiliser off-field.[1,2] Current nutrient management practices using chemical fertilisers exhibit adverse environmental effects. Continuous production of crops under intensified agriculture over years, has resulted in large-scale removal of nutrients from soil, thereby causing a negative nutrient balance and declining soil fertility.[3] Hence, an adequate proportion of nutrient supply, especially in the form of bio-fertilisers, to soil and/or crops is essential for enhancing global food security.[4] Long-term irrigation with wastewater may result in the accumulation of heavy metals in soils and plants, consequently decreasing food safety and increasing health risk, which are environmental concerns.[5,6] Health risks caused by heavy metal contamination of soil have been widely reported.[7–12] Crops and vegetables grown in soils contaminated with heavy metals may have a larger accumulation of metals than those grown in uncontaminated soils. Risk assessment of heavy metal accumulation in wastewater irrigated leafy vegetables, such as palak (*Beta vulgaris* L.), amaranthus (*Amaranthus caudatus* L.), and cabbage (*Brassica oleracea* L.) was reported by Anita et al.[6] Intake of metal-contaminated vegetables is a pathway for heavy metal toxicity to humans.[13,14] Intawongse and Dean[15] determined the bioavailability of Cd, Cu, Zn and Mn in the human gastrointestinal tract from the edible part of the vegetables by using an in-vitro gastrointestinal extraction technique. They found that the edible portions of 'lettuce and radish' are more responsible than other vegetables for heavy metal accumulation in humans.

Malaysia has approximately 260 landfills, of which 10% are engineered (safe collection and leachate treatment facilities) and 90% are un-engineered.[16] Agamuthu[16] indicated that the volume of leachate generated is about 3 million litres per day. Leachate is produced by precipitation and percolation of 'biodegradable and non-biodegradable' wastes deposited in landfills. Landfill leachate mainly consists of large amounts of organic matter, including dissolved organic matter, phenols, ammoniacal nitrogen, phosphates, heavy metals, sulfides, solids, inorganic salts, and other toxicants, and is characterised by hardness, acidity, alkalinity, and salinity.[16,17] The complex pollution and toxicity impacts of leachates have imposed the need to standardise pre-treatments prior to discharge for quality improvement.[18] Treated leachates contain nutrients and minerals that can possibly be transformed for fertigation. Scholars have reported N transport and distribution characteristics in soils for basin irrigation using fertigation and conventional fertilisation.[19-21,5] Cheng and Chu[22] reported the positive and detrimental effects of landfill leachate on plant growth, depending on plant species leachate concentration. Menser et al.[23] explained that irrigation with leachate can lead to yield reduction, leaf damage, premature senescence and poor plant survival. By contrast, Liang et al.[24] suggested that the use of landfill leachate as irrigation water in dry seasons can enhance the growth, survival, and stomatal conductance of *Acacia confusa*, *Leucaena leuocephala* and *Eucalyptus torelliana*. Cureton et al.[25] reported significantly high growth rates of *Phalaris arundinacea*, *Salix babylonica* and *Populus nigra* subjected to leachate application; however, phytotoxicity symptoms, such as brown leaves and necrotic spots, were observed in poplar leaves. Mapanda et al.[26] reported that more than 100 ha of land under horticultural production in Harare utilises wastewater for irrigation of crops such as maize (*Zea mays*) and leafy vegetables (*Brassica* spp.). Growth rate and biomass production are common indicators of imposed stress. Although leaf length, leaf width and shoot length exhibit fluctuating asymmetry, non-directional deviation from anticipated symmetry is proposed as an environmental stress indicator.[27,28] Nominal consumers consider undamaged, dark green and large leaves as characteristics of good-quality leafy vegetables; however, the external morphology of vegetables cannot guarantee safety from contamination. In particular, heavy metals rank the highest among the chief contaminants of leafy vegetables.[26,29,30]

Leafy vegetables grow in places with adequate water supply and well-drained, fertile and preferably alkaline soils. These plants prefer a pH range of 5.5–8.2 although they can tolerate a pH within the range of 4.3–7.5.[31] Leafy vegetables prefer cool, moist and reasonably fertile soils. Shallow rooted plants are intolerant of drought and thus need to be grown in moist, fertile soil to produce high-quality leaves.[32] *Brassica* and mustards need adequate nitrogen and sulfur[33] and an N:S ratio ranging from 4:1 to 8:1 is appropriate for the *Brassica* species. Treated landfill leachate can be utilised as a source of water or plant nutrients, and as a soil conditioner for crop production.

This study aimed to characterise leachate from the Ampar Tenang landfill and compare its performance with conventional inorganic fertiliser at different leachate concentrations for fertigation. The yields of *Brassica* at specific N concentrations in leachates and inorganic fertiliser were analysed to ascertain the effects of nutrients on plants and to compare them with the permissible concentration standards set by the Ministry of Agriculture, Fisheries and Forest, United Kingdom and the Food and Agricultural Organization of the United Nations/World Health Organization (FAO/WHO).

Materials and method

Site description

The Ampar Tenang landfill, located in the Sepang district of Selangor, Malaysia, began its operations in the year 2000 and was closed on 26 January 2010. Under the management of Alam Flora Sdn. Bhd., a waste management company, the 4-ha landfill received about 150 tonnes of domestic waste daily from Sepang and its environs. Leachate from this landfill indiscriminately leached into nearby un-engineered 'erosion' holes after precipitation.

Analysis of leachates

Specific characteristics of the leachate are displayed in Table 1. The pH and conductivity of the leachate were measured using a pH and conductivity probe (Hanna Model, No. 8033, Clarkson Laboratory, Chula Vista, CA, USA.). Total suspended solids and colour were determined using a spectrophotometer (HACH Model, DR/4000, Hach Company, Loveland, CO, USA). Biochemical Oxygen Demand (BOD_5), Chemical Oxygen demand (COD), and total-N were analysed according to the standard methods of the America Public Health Association (APHA), the America Works Association (AWWA) and the Water Environment Federation (WEF), respectively.[34] Heavy metals were determined in digested leachate by inductively coupled plasma optical emission spectrometry. The leachate was chemically treated using a Jar Test which involves a six-paddle flocculator, from Stuart Scientific (Stone, UK) equipped with 6 beakers of 500 mL each. Ferric (III) chloride at 4 g/L in solid state was used as effective coagulant dosage for raw leachate at pH 7.[35] The filtrate was used for fertigation treatments.

Table 1: Characteristics of untreated leachate samples from Ampar Tenang landfill compared with Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulation 2009 Malaysia[49]: Acceptable conditions for discharge of leachate.

Parameters	Units	(Ampar Tenang landfill leachate)	Standard	Method
Temperature	°C	29.8± 0.031	40	APHA2550B
pH at 25°C	–	6.58± 0.522	6.0-9	0APHA4500-H⁺B
BOD_5	mg/L	209± 2.101	20	APHA2550B
COD	mg/L	3150± 3.521	400	APHA2550C
BOD_5/COD ratio	mg/L	0.07± 0.005	–	–
Chloride	mg/L	2671±18	NA	HACH8113
Turbidity	FAU	1260± 2.610	NA	APHA2540D
Sulfate	mg/L	221± 1.501	0.5	HACH 8131
Total N	mg/L	900± 0.00	5.0	APHA4500-N
Suspended Solid	mg/L	1718± 2.120	50	APHHA 2540D
Oil and Grease	mg/L	411.5± 0.001	5.0	APHA5520B
K	mg/L	3575±2.531	N.A	APHA3120B
Ca	mg/L	85±4.021	N.A	APHA3120B
Mg	mg/L	18.8±0.232	N.A	APHA3120B
Na	mg/L	1352±1.012	N.A	APHA3120B
Pb	mg/L	0.25±0.001	0.10	APHA3120B
Cd	mg/L	0.000001±0.001	0.01	APHA3120B
Se	mg/L	1.6±0.011	0.02	APHA3120B
Al	mg/L	19±1.201	N.A	APHA3120B
Mn	mg/L	6.75±0.170	0.2	APHA3120B
Cu	mg/L	0.245±0.011	0.2	APHA3120B
Zn	mg/L	2.35±0.003	2.0	APHA3120B
Fe	mg/L	15±0.111	5.0	APHA3120B
As	mg/L	0.3±0.002	0.05	APHA3120B
P	mg/L	45± 0.00	N.A	HACH8048

N.A, not available; BOD, Biochemical Oxygen Demand; COD, Chemical Oxygen Demand

Experimental design and growth conditions

The study was conducted in a designed greenhouse (1.2 m x 1.2 m x 3.3 m) near the IGS building, University of Malaya. *Brassica rapa* L. were grown in free-draining 4-L nursery poly bags, each containing 5 kg of soil, classified as Mollisol[36] (Table 2). Ten seeds were sown in germination pots to which distilled water of pH 6.94 (without metal contaminants) was applied daily. At day 6 after germination, uniform seedlings were selected and transplanted at a rate of two plants per bag (0.2 m x 0.2 m), spaced 8 cm apart to reduce inter-plant competition for nutrients. All plants were watered well daily until leachate application began on day 19 after seed germination. At this time, the plants had an average leaf length of 3.5 cm, 2.5 cm leaf width and 2.8 cm root length, as determined by destructive sampling. The experiment progressed for three consecutive growing seasons and the measured parameters were averaged over this period of analysis.

Nine treatments (Table 3) were imposed in a randomised complete block (RCB) design with stringent elimination of weeds. Each treatment contained two plants per bag with three replicates. Both 100% raw and treated leachate presented the same total N contents (0.090 N), whereas the 75–12.5% diluted treated leachate (DTL) contained 0.068–0.012% N. The N content of 50% DTL and 100% inorganic fertiliser (IF) was standardised at 0.045% N. For each treatment, 200 mL of leachate was applied by dripping twice a day (before 8:00 and after 17:00) until the plants expanded. At this time, higher evapotranspiration occurred and thus fertigation was increased to 250 mL (twice a day) to ensure 70% soil water holding capacity. The total leachate treatment period was 36 days. No pesticide was applied to the plants until the end of the experiment.

After day 56 (which is equivalent to 36 consecutive days of leachate application), the plants were harvested by uprooting. Fresh weights of leaves, stems and roots were determined, as well as total leaf number. Leaf length (LL), leaf width (LW) and stem height (SH) were measured prior to harvesting and root length was measured immediately after harvest.

The leaves, stems, and roots were dried at 70 °C in a forced draft oven (GO-251, Durham Geo-Enterprises Inc. Stone Mountain, GA, USA) for 3 days until constant weight to determine dry matter yield. All data generated were subjected to statistical analysis with one-way analysis of variance (ANOVA) using SPSS 17.0. Specific growth rate for leaf length, leaf width root length, and stem height were determined using the equation stated by Dimitriou et al.[37]:

$$\text{Specific growth rate} = \frac{\ln L_2 - \ln L_1}{t_2 - t_1} \text{(mm/day)} \qquad \text{Equation 1}$$

where L_1 and L_2 are the initial and final lengths at the exponential phases, respectively and t_1 and t_2 are the initial and final selected time intervals, respectively. Data were analysed using ANOVA and Microsoft Excel.

Heavy metal analysis

After drying, the weight of the plant and soil samples was recorded to the nearest gram. The samples were individually mashed to pass through the 2 mm screen in a laboratory mill (Serial no. 39017, Christy and Norris LTD, Chelmsford, England) and then 1 g of the sample was accurately weighed and placed into a 500 mL volumetric flask. For the plant samples, 1 mL of 65% HNO_3 and 10 mL of distilled water were added into the 500 mL volumetric flask and refluxed for 10 min by mounting the flask on a digestion heater (EAM9203 heating mantle, Camlab Ltd., Cambridge, UK) at 105 °C. Another 5 mL of 65% HNO_3 was added after 15 min and the mixture was allowed to digest until the solution became transparent. For the soil samples, 3 mL of (30%) H_2O_2 and 10 mL of HCl were added into the 50 mL volumetric flask while refluxing for 15 min. The resulting solutions were allowed to cool before being filtered and diluted with 50 mL of deionised water. The solutions were analysed for K, Ca, Mg, Na, Pb, Cd, Se, Al, Mn, Cu, Zn, Fe and As through inductively coupled plasma optical emission spectrometry.

Table 2: Physicochemical characterisation of the Mollisol soil prior to fertigation

Parameters	Soil	MAFF standard [(mg/kg)[44,45]	Methods
Clay (%)	25	–	Laboratory method (PSA)
Silt (%)	55	–	Laboratory method (PSA)
Sand (%)	20	–	Laboratory method (PSA)
Moisture (%)	40	–	Gravimetric analysis
pH	6.02	–	APHA 4500-H^+B
Total Nitrogen (%)	1.10	–	Kjeldahl method
Phosphorus (%)	21.8	–	USEPA 3050B
CEC (meq/100g)	36.90	–	Protocol HRN ISO 11260:2004
K (mg/kg)	9.11	–	USEPA 3050B
Ca (mg/kg)	44.73	–	USEPA 3050B
Mg (mg/kg)	5.83	–	USEPA 3050B
Na (mg/kg)	4.68	–	USEPA 3050B
Pb (mg/kg)	>0.06	0.19	USEPA 3050B
Cd (mg/kg)	>0.01	0.07	USEPA 3050B
Se (mg/kg)	>0.05	–	USEPA 3050B
Al (mg/kg)	1.85	–	USEPA 3050B
Mn (mg/kg)	8.85	–	USEPA 3050B
Cu (mg/kg)	2.71	2.9	USEPA 3050B
Zn (mg/kg)	0.65	0.16	USEPA 3050B
Fe (mg/kg)	30.47	–	USEPA 3050B
As (mg/kg)	>0.01	0.16	USEPA 3050B

PSA, particle size analysis

Table 3: Leachate treatment applications used the in experiment

Treatments	Details of Treatments
100%RL	100% Raw Leachate
100%TL	100% Treated Leachate
75% DTL	75% Treated Leachate +25% distilled water
50%DTL	50% Treated Leachate + 50% distilled water
50%DTL+50%IF	50%Treated Leachate + 50% Inorganic Fertilizer
25% DTL	25% Treated Leachate + 75% distilled water
12.5%DTL	12.5% Treated Leachate + 87.5% distilled water
100%IF	Inorganic Fertilizer N: P: K + 100 % distilled water
dH_2Ocontrol	100% Distilled Water (Control)

DTL, diluted treated leachate; TL, treated leachate; IF, inorganic fertiliser; RL, raw leachate

Results and discussion

Overview of leachate characteristics for fertigation

The total N content of the raw leachate sample was 900 mg/L (Table 1). The high N concentration can be attributed to the breakdown of nitrogenous substances during organic waste decomposition.[38] The Amper Tenang landfill leachate exhibited typical characteristics of an ageing methanogenic landfill with a BOD_5/COD ratio between 0.06 and 0.08 and pH within the range of 6.12–7.04. Christensen et al.[39] described this as a characteristic of an ageing landfill. The high suspended solid level in the leachate may be attributed to the presence of organic and inorganic compounds.[17]

After leachate treatment with 4 g/L $FeCl_3$ at pH 7, the contents of Cd, Al, Fe, Pb, Cu and Zn decreased by 100%, 64.4%, 51.9%, 82%, 56.8% and 96.6%, respectively. The optimal removal capacity for suspended solids (SS) was 80%. Hamidi et al.[40] reported the same dosages with similar reduction effects on colour, turbidity, and SS.

Plant physical growth evaluation

B. rapa L. survived until harvest, although common symptoms of soil salinisation such as chlorosis and leaf burn were noticed on 100%RL to 100%TL. This finding was not observed in plants irrigated with 75%DTL–12.5%DTL, probably because of the changes and/or decrease in concentration gradient. Plants receiving 25%DTL produced significantly longer leaves (23.17±0.577 cm) than those in the other treatments ($p<0.05$) (Table 4). Plants treated with 25%DTL presented wider leaves, with 1.36 and 3.23 times higher width than plants receiving inorganic fertiliser [100% IF (N_{15}:P_{15}:K_{15})] and the control. Less expanded leaf length and width were also observed in plants treated with the control compared with those in other treatments, which may be a clear indication of nutrient deficiency and differential N proportions.[41,37] Overall, 25%DTL could be the optimal nutrient requirement level for leaf expansion of *B. rapa* L. (Table 5), at a specific growth rate of 0.53 mm/day.

Table 4: Comparison of leaf length, leaf width, stem height and total leaf number for *Brassica rapa* L. after 56 days

Treatments	Leaf length (cm)	Leaf width (cm)	Stem height (cm)	Total leaf number*(not in cm)
100%RL	19.17 ± 0.577^{zcfg}	9.00 ± 0.866^{z}	2.44 ± 0.323^{z}	16.17 ± 1.893^{zdeh}
100%TL	19.50 ± 1.323^{zcfgh}	9.83 ± 1.155^{zh}	2.23 ± 0.322^{x}	18.67 ± 1.610^{zcdefh}
75%DTL	15.72 ± 1.114^{z}	8.33 ± 1.258^{z}	2.43 ± 0.416^{z}	14.33 ± 0.764^{z}
50%DTL	19.00 ± 1.803^{zcf}	9.00 ± 0.500^{z}	2.27 ± 0.306^{x}	12.00 ± 1.323^{z}
25%DTL	23.17 ± 0.577^{zybcdfgh}	10.33 ± 0.289^{zch}	2.30 ± 0.361^{x}	12.33 ± 1.041^{z}
12.5%DTL	15.67 ± 1.041^{z}	9.33 ± 1.443^{z}	2.17 ± 0.379^{x}	15.17 ± 2.363^{zde}
50%DTL+50%IF	16.83 ± 2.021^{z}	9.17 ± 1.155^{z}	2.50 ± 0.866^{x}	16.33 ± 1.607^{zdeh}
100%IF	17.00 ± 1.500^{z}	7.67 ± 0.764^{z}	2.50 ± 0.866^{x}	13.23 ± 1.662^{z}
dH_2O	7.17±0.577	4.50±1.803	1.50±0.500	8.33±0.764
TOTAL	**153.23±16.533**	**77.16±18.466**	**20.33±4.339**	**126.56±13.027**
Levels of significance:	**p<0.05 at F=35.256**	**p<0.05 at F=7.035**	**p<0.05 at F=1.03**	**p<0.05 at F=11.651**

DTL, diluted treated leachate; TL, treated leachate; IF, inorganic fertiliser; RL, raw leachate

Letters indicate statistical significance between different treatment levels using analysis of variance (ANOVA) version SPSS 17.0.

Table 5: Specific growth rate comparison for *Brassica rapa* L. at harvest after 56 days

Treatments	Leaf length (mm/day)	Leaf width (mm/day)	Stem height (mm/day)	Root length (mm/day^{-day})
100%RL	0.47	0.35	0.22	0.30
100%TL	0.48	0.38	0.22	0.42
75%DTL	0.42	0.33	0.22	0.40
50%DTL	0.46	0.35	0.20	0.38
25%DTL	0.53	0.39	0.21	0.30
12.5%DTL	0.42	0.37	0.19	0.40
50%DTL+50%IF	0.43	0.36	0.23	0.35
100%IF	0.44	0.31	0.23	0.42
dH_2O	0.20	0.16	0.09	0.21
TOTAL	**3.87**	**3.02**	**1.79**	**3.18**

DTL, diluted treated leachate; TL, treated leachate; IF, inorganic fertiliser; RL, raw leachate

Dry biomass weight evaluation

B. rapa L. that received 50%DTL+50%IF presented 2.25 and 1.60 times higher dry weight of leaf biomass than plants treated with the control and 100%IF (Table 6). This phenomenon may be attributed to the synergistic effect of N, which enhanced moisture retention in plants treated with 50%DTL+50%IF plants.[42] Statistical comparison showed that leaf dry weights were not significantly different for plants treated with 50%DTL+50%IF and those treated with 25%DTL $p<0.05$, which could be because of equal moisture contents and/or evapotranspiration rates during fertigation.[43] The dry root biomass of plants treated with 25%DTL was 3.16 and 1.70 times higher than that of plants treated with the control and 100%IF, respectively (Table 6). Initial low biomass yield, moisture content in the control and optimum growth nutrient requirements may be the implicating and/or limiting factors. Dry stem biomass was 5.48 times lower in control plants (0.25±0.050 g) than that in plants with 100%RL (1.37±0.176 g, $p<0.05$). The zero N supplementation during fertigation hindered the yield and subsequent biomass.

Heavy metal analysis in soil and plants, pH impact and N dynamics

The overall concentrations of heavy metals present in the soil prior to fertigation were lower than the detection and maximum permissible limits.[44,45] Application of leachate generally altered the physicochemical characteristics of the soil and the heavy metal uptake by vegetables.[46,6] A comparison between edible (plant) parts, namely, shoots collected 1 cm above the soil surface, showed that plants treated with 50%DTL and 100%IF and market samples of *B. rapa* L. (as control), contained zero Cd (Tables 7 and 8), while the permissible limit for Cd is 0.2 mg/kg.[47,48]

Table 6: Dry leaf, root and stem weights of *Brassica rapa* L. after 56 days

Treatments	Leaf (dry wt.) g	Root (dry wt.) g	Stem (dry wt.) g
100%RL	2.80 ± 0.427^{zcd}	91 ± 0.553^{zcdfgh}	1.37 ± 0.176^{zcdefgh}
100%TL	2.55 ± 0.247^{zd}	3.30 ± 0.500^{zcdfgh}	1.21 ± 0.110^{zdefh}
75%DTL	2.22 ± 0.475^{x}	1.18 ± 0.457^{x}	1.00 ± 0.474^{zdefh}
50%DTL	1.95 ± 0.377^{x}	0.95 ± 0.182^{x}	0.33 ± 0.11^{x}
25%DTL	3.60 ± 0.304^{zybcdfh}	3.60 ± 0.654^{zycdfgh}	021 ± 0.015^{x}
12.5%DTL	2.67 ± 0.301^{zd}	1.25 ± 0.050^{x}	0.58 ± 0.104^{e}
50%DTL+50%IF	3.95 ± 0.050^{zybcdfh}	1.33 ± 0.104^{x}	0.93 ± 0.104^{zdefh}
100%IF	2.48 ± 0.225^{z}	2.11 ± 0.202^{zcdfg}	0.33 ± 0.029^{x}
dH_2O	1.75±0.180	1.14±0.051	0.25±0.050
TOTAL	**23.97±2.586**	**17.77±2.753**	**6.21±1.178**
Level of significance:	$p>0.05$ at F=15.876	$p>0.05$ at F=24.543	$p>0.05$ at F=17.25

DTL, diluted treated leachate: TL, treated leachate: IF, inorganic fertiliser: RL, raw leachate

Letters indicate statistical significance between different treatment levels using analysis of variance (ANOVA) version SPSS 17.0.

Table 7: Metal content comparisons of 50% diluted treated leachate (DTL) with 100% IF treatment levels with both (water and market) controls for *Brassica. rapa* L. after 56 days

Metals	50%DTL (mg/kg)			100%IF (mg/kg)			dH_2O Control (mg/kg)			Market Vegetable Control (mg/kg)		
	Shoot	Root	Soil	Shoot	Root	Soil	Shoot	Roots	Soil	Shoot	Root	Soil
K	42.84±4.1	3.16±4.3	1.21±0.0	62.89±3.9	3.27±2.0	1.31±0.2	0.95±0.3	1.84±0.2	1.31±0.0	12.46±2.2	11.24±3.1	–
Ca	18.35±2.9	14.06±3.7	5.32±0.1	41.99±4.0	2.56±0.9	6.06±0.2	0.22±0.1	1.26±0.1	5.7±0.4	6.6±1.2	3.43±0.8	–
Mg	5.65±0.03	4.85±0.5	0.92±0.0	5.74±1.4	4.96±1.2	1.83±0.1	3.06±0.8	5.73±0.5	2.04±0.0	1.78±0.2	10.85±0.2	–
Na	41±02±3.2	30.40±4.4	5.29±0.1	15.53±1.4	2.93±1.9	6.03±0.1	2.16±1.0	2.93±0.2	2.97±0.0	5.26±2.1	3.65±0.1	–
Pb	0.09±0.12	0.41±0.3	0.00±0.0	0.07±0.10	0.19±0.1	0.00±0.0	0.00	0.00	0.00	0.00	0.00	–
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	–
Se	1.36±0.10	1.97±0.2	1.50±0.0	0.12±1.2	1.24±0.0	1.35±0.3	0.04±0.0	0.04±0.0	1.23±0.0	1.15±0.0	1.09±0.0	–
Al	20.05±3.5	16.11±2.7	3.12±0.0	0.83±2.3	3.49±1.6	2.62±0.0	4.55±0.7	4.80±0.8	5.69±0.2	4.55±0.0	4.80±0.8	–
Mn	0.43±0.22	0.49±0.1	0.07±0.0	0.18±0.4	0.43±0.0	0.13±0.0	0.17±0.1	0.08±0.0	0.15±0.0	1.22±0.2	0.20±0.0	–
Cu	0.16±0.02	0.25±0.0	0.07±0.01	0.01±0.36	0.20±0.2	0.02±0.0	0.04±0.0	0.03±0.0	0.09±0.0	0.10±0.0	0.07±0.0	–
Zn	0.82±0.47	1.16±0.1	0.32±0.00	0.23±1.56	1.29±0.4	0.40±0.0	0.40±0.1	0.33±0.1	1.00±0.0	0.90±0.1	0.34±0.1	–
Fe	8.82±4.15	9.98±0.4	0.37±0.00	0.91±2.55	2.51±2.8	0.28±0.0	4.34±0.4	4.00±0.4	0.93±0.0	4.11±1.1	6.50±1.2	–
As	0.08±0.03	0.08±0.0	0.12±`0.00	0.03±0.08	0.06±0.0	0.12±0.0	0.07±0.0	0.08±0.0	0.17±0.0	0.17±0.0	0.09±0.0	–

Table 8: Food and Agricultural Organization of the United Nations/World Health Organization (FAO /WHO) heavy metal permissible limits in vegetables

Metals	FAO/WHO (mg/kg)
K	N.A
Ca	75
Mg	N.A.
Na	N.A.
Pb	3
Cd	0.2
Se	N.A.
Al	N.A.
Mn	0.2
Cu	40
Zn	60
Fe	N.A.
As	1.0

N.A, not available

Source: FAO/WHO (Codex Alimentarius[47,48]).

Traces of Pb ranging from 0.07–0.09 mg/kg were detected in *B. rapa* L. edible parts treated with 50%DTL and 100%IF, whereas zero Pb content was observed in the market sample. Nevertheless, Pb concentration was still lower than the maximum permissible concentration of 3 mg/kg. Moreover, arsenic content was lower than the maximum permissible concentration limit of 1.0 mg/kg, as proposed by the Food Quality and Standard Control Division, Ministry of Health Malaysia[49] for heavy metals under the Malaysia Standard.

Large amounts of K, Ca, Mg, Na, Al, and Fe accumulated in the edible parts of *B.rapa* L. treated with 50%DTL were compared with those in the market sample, but the concentration of these elements was still within the acceptable range. This result is in agreement with a previous study by Liu et al.[50] that reported increased levels of metals in edible parts of food crops that were continuously irrigated with wastewater. Conventional wastewater treatment processes concentrate sludge fractions with accumulated heavy metals, thereby producing pure water with minimal metal concentrations.[51] The results of this study were obtained solely from a greenhouse experiment and should therefore be verified with field studies before being advocated to farmers. Long-term fertigation with landfill leachates may improve soil health conditions because of the fertiliser effect and provide economic benefits to farmers. However, this process may present certain limitations, particularly in terms of soil salinisation, N oversupply, heavy metal leaching to ground water and food chain contamination.[51]

The soil pH was 6.02 ± 0.01 before fertigation began and then decreased to 6.0 ± 0.001 and 6.01 ± 0.002 for the undiluted (100%) and diluted (12.5–75%) treatments, respectively. Cation exchange capacity, clay fraction, and soil organic matter were implicated in influencing the buffering system in acid soils, as reported by Jiang et al.[52] N incorporation from leachate was assumed to be responsible for the decrease in pH. A field inquiry performed by Van Breemen et al.[53] and Huang et al.[54] indicated that 500 kg N/ha per year as urea is commonly applied the for production of *B. rapa* L. Based on this urea content, which is equivalent to 35.7 kmol N/ha per year, the estimated N input to 5 kg of Mollisol in a poly bag is 0.14 kmol N kg/ha per year. As the N concentration of undiluted leachate (100%) was 0.09% and that of diluted leachate (12.5–75%) ranged from 0.012–0.068%, the increase in H^+ protons$_{(pro)}$ caused by nitrification (Ni), amounted to 0.013 and 0.002 to 0.009 kmol kg/ha per year respectively, as calculated using Equation 2[55]:

$$H^+_{(pro)}\ (Ni) = 0.14 \times \%\ N_{(Leachate)}\ \text{kmol kg/ha per year} \qquad \text{Equation 2}$$

Thus, N use efficiency from harvested plants in the undiluted (100%) and diluted (12.5–75%) leachate treatments amounted to 40% and 60%, respectively. Hence, H^+ proton deposition$_{(dep)}$ in soil calculated using Equation 3,[56] was 0.06 and 0.08 kmol kg/ha per year for the undiluted diluted leachates, respectively.

$$H^+_{(dep)}\ (uptake) = 0.14 \times \%N_{(utilised)} \qquad \text{Equation 3}$$

The duration (1/T) for a unit decrease in soil pH on account of leachate treatments was estimated with Equation 4:

$$1/T = H^+_{(dep)} \times \text{Bulk Density [BD} = 0.02\text{: mass (5 kg)/vol. (250mL)]} \qquad \text{Equation 4}$$

For the undiluted (100%) and diluted (12.5–75%) leachates, the estimated duration was 625 years and 833 years, respectively. The soil acidification rate induced by N fertigation with leachate was approximately 0.01 unit pH/year.

Conditions such as extreme biogeochemical/anthropogenic disruptions in the soil ecosystem may alter and/or decrease soil pH and enhance cation bioavailability and desorption from soil matrices. In cases with rapid changes in soil pH because of fertigation with leachate, application should be terminated and waste composition from the leachate source, treatment facility, and concentrations applied to soil should be re-evaluated.

Generally, *B. rapa* L. exhibits higher mineral accumulation tendencies at their leaf region. This study revealed that K, Ca, Mg, Na, Al, and Fe were the most dominant minerals present in the plant. Pb and Cd concentrations were lower than the permissible levels.

Conclusion

This study attested that treated landfill leachate, similar to inorganic fertiliser, can be an effective source of nutrients for irrigated *B. rapa* L. Leachates can be recycled and utilised as bio-fertiliser for edible and non-edible plants, even for ornamental and timber species. The heavy metal levels in the treated leachate-grown *B. rapa* L. were lower than the stipulated permissible concentrations based on the FAO/WHO standards. Therefore, this treatment strategy will reduce the impact of chemical fertilisers on our ecosystem.

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Authors' Contributions

F.O.A. was the principal researcher, while the P.A. was the project head and investigator. Both authors collaborated effectively to complete the study.

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