CHEMICAL ENGINEERING TRANSACTIONS

VOL. 76, 2019

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar S. Varbanov, Timothy G. Walmsley, Jiří J. Klemeš, Panos Seferlis

ISBN 978-88-95608-73-0; **ISSN** 2283-9216

DOI: 10.3303/CET1976229

Nutrient in Leachate of Biowaste Compost and its Availability for Plants

Nur Farzana Ahmad Sanadi[a], Yee Van Fan[b], Chew Tin Lee[a,*], Norahim Ibrahim[c], Chunjie Li[d], Yueshu Gao[d], Pei Ying Ong[e], Jiří Jaromír Klemeš[b]

[a]Department of Bioprocess Engineering, School of Chemical and Energy Engineering Universiti Teknologi Malaysia (UTM) 81310 UTM Johor Bahru, Johor, Malaysia
[b]Sustainable Process Integration Laboratory – SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology - VUT Brno, Technická 2896/2, 616 69 Brno, Czech Republic
[c]School of Biomedical Engineering and Health Science Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor, Malaysia
[d]School of Environmental Science and Engineering, Shanghai Jiao Tong University, 800 Dong Chuan Road, Minhang District, Shanghai 200240, China
[e]Innovation Centre in Agritechnology for Advanced Bioprocessing (ICA), Universiti Teknologi Malaysia - Pagoh, Jalan Edu Hub UTM 2, Hub Pendidikan Tinggi Pagoh, 84600 Pagoh, Johor Darul Takzim
ctlee@utm.my

Compost leachate (CL) is a liquid by-product of compost that contains carbon, nitrogen, phosphorus, potassium and trace elements. It can partially replace the commercial liquid fertilisers to promote plant growth. However, CL may contain heavy metals, phytotoxic substances such as ammonia, organic compounds of low molecular weight, high level of salt and oils. Treatment of leachate is required to avoid the damage on the plant. This paper aims to review the nutrient and physical characteristics of the CL from three types of bio-wastes, i.e. municipal solid waste, animal waste and green waste. The effects of plants treated with CL in terms of rate and nutrient absorption were discussed. The nutrient and physical composition of the leachate is highly variable due to the diversity of the sources and age of the leachate. Compost leachate from municipal solid waste contains the highest chemical oxygen demand (COD) (15,188 – 105,300 mg/L) followed by those from animal waste (6,542 – 100,000 mg/L) and green waste (804 – 1,152 mg/L). The difference in COD is due to the difference in organic carbon content in the biowaste. Other physical parameters, such as electrical conductivity and pH, are correlated with the organic carbon content. For nutrient composition, municipal solid waste leachate contains the highest nitrogen content (630 – 2,438 mg/L), green waste has the highest potassium content (500 – 1,000 mg/L), while animal waste has the highest phosphate content (170 – 500 mg/L). The nutrient contents of CL derived from different biowaste reviewed in this study serves as a guideline for users to estimate the dilution rate and further nutrient formulation required for the application of CL on plants.

1. Introduction

Urban agriculture has gained increased attention for the delivery of fresh food around the urban area (Mougeot, 2000). Due to low soil quality and limited land, urban communities use soilless planting system such as hydroponic system. Soilless planting system uses liquid fertiliser as a nutrient medium to replace the conventional solid fertiliser (Eigenbrod and Gruda, 2015). Compost leachate (CL) is a liquid by-product of compost. It contains major nutrients such as carbon source (C), nitrogen (N), phosphorus (P), potassium (K) and trace elements that could provide the essential nutrients for plants (Romero et al., 2013). CL contains humic acids, which are known to increase plant growth (Arancon et al., 2003) by controlling the micronutrient and macronutrient absorption (Atiyeh et al., 2002). However, high nutrient concentration in CL may damage the plant due to phytotoxicity (Hashemi and Khodabakhshi, 2016). Fresh CL contains phytotoxic substances such as ammonia, organic compounds of low molecular weight and/or high salt content (Zhang et al., 2009). Dilution of CL is recommended to reduce plant damage, but this decreases its nutrient content. A detailed study of CL such

Paper Received: 09/05/2019; Revised: 14/07/2019; Accepted: 03/08/2019
Please cite this article as: Sanadi N.F.A., Fan Y.V., Lee C.T., Ibrahim N., Li C., Gao Y., Ong P.Y., Klemes J.J., 2019, Nutrient in Leachate of Biowaste Compost and its Availability for Plants, Chemical Engineering Transactions, 76, 1369-1374 DOI:10.3303/CET1976229

as the physical and nutrient properties from different biowaste is still limited, and more research is needed to utilise CL in an optimal way. This study aims to review and characterise the physical and nutrient composition of CL from three biomass, i.e. from the municipal solid waste (MSW), animal waste and green waste. The outcome of the review is crucial to capitalise the optimal utilisation of liquid waste from biowaste.

2. Materials and methods

2.1 Review scopes on CL

Previous studies reported the physical and nutrient characteristics of the CL and the corresponding nutrient uptake rate by the plant. However, a study to review the physical and nutrient content of the CL from different biowaste source and the dilution rate required for plant application is still unclear. This study reviewed the physical and nutrient composition of CL from three sources of biowaste, namely i) two types of MSW CL: from the untreated landfill site (untreated MSW) and CL generated from the organic portion of MSW (OP-MSW) composting plant ii) CL from animal manure such as goats, cows and chicken; iii) CL from the green waste such as from the lawn clippings, grasses and green leaves of vegetables. The untreated MSW CL was collected from the untreated landfill site (>10 y), which comprised of mixed MSW (inorganic and organic) (2,800 – 4,000 t/d). The composted OP-MSW CL was collected from the windrow composting centre, i.e. the leachate runoff pond. The animal and green waste based compost and CL are collected from the composting site. CL from these biowastes were characterised regarding the macro-nutrients (nitrogen (N), phosphorus (P) and potassium (K)), trace elements (copper (Cu), nickel (Ni), lead (Pb), zinc (Zn) and iron (Fe)) and the physical properties such as pH, electrical conductivity (EC), and Chemical Oxygen Demand (COD). This study also reviewed the application of CL as a liquid fertiliser and its effects on the plant. The plants are classified based on the size, namely i) small plant species; consist of fruits and flower crops that grow at an average height 61 cm for shorter and ii) large plant species; consist of grains and trees species that grows at an average height of 1 – 10 m . The nutrient content of the plant will be reviewed on three parts, i) soil and root area, ii) shoot and leaves the area, and iii) fruits and grains area. The relationship between the nutrient level of CL applied, and its effects on the nutrient uptake by the plant were reviewed.

2.2 Literature search and selection criteria

A systematic literature review and screening were conducted in the databases of Science Direct® and Scopus®. The search considered the indexed papers published between the year 2002 and 2018 with at least one of these keywords: composting, compost, leachate, animal manure, landfill waste, green waste, plant growth, nutrient uptake, agriculture waste, municipal solid waste, liquid fertiliser, foliar.

3. Result and discussion

3.1 Physical and nutrient characteristic of CL

Table 1 shows the physical and nutrient characteristics of CL from different biowaste. CL from OP-MSW compost contains the highest COD range (15,188 – 105,300 mg/L) followed by those from animal and green waste. The high COD value in the CL is due to the organic matter content in the liquid (Mokhtarani et al., 2012). The low COD in green waste CL may vary due to the lower biodegradability of the cellulosic biomass. CL from the untreated MSW landfill recorded the lowest COD reading (987 – 1,041 mg/L) compared to the CL generated from the OP-MSW compost. The low COD of the untreated MSW landfill may be due to the age of the landfill. Foo and Hameed (2009) reported that CL from the old (>10 y) untreated MSW landfill has a COD of <4,000 mg/L. During the methanogenic stage, volatile fatty acids (VFA) would be converted into methane and carbon dioxide (CO_2), reducing the COD level (Sigh et al., 2016). CL from the untreated landfills (5 – 10 y) has a COD range of 4,000 – 10,000 mg/L, which is considered low (Foo and Hameed, 2009).

CL from the freshly composted mixed MSW (fresh – 7 d) has a lower pH range (3.8 – 6.98) compared to that from the older composted MSW CL (30 d, 8.0). The CL from the fresh green waste (2 d) has recorded a slightly acidic (5.1) pH as compared to the older green waste leachate (pH 7.1 – 8.79, more than 3 d). The acidic nature of the fresh CL is due to the high concentration of VFA released at the initial stages of composting. As the compost reached a high temperature (>60 °C), VFAs will be converted into methane and CO_2, so the pH of CL would become alkaline (Yang et al., 2019). CL from the untreated MSW (>10y) landfill CL also has an alkaline pH range (7.14 – 9.05) due to the reduction of VFA (Foo and Hameed, 2009). Animal waste CL has a neutral pH range (6.0 – 8.4) in both the fresh and old CL showing that animal dungs are digested (partly degraded) within the animal body. Variation of pH in the CL is due to the differences in the organic carbon and nitrogen contents in the biowaste.

CL from both the untreated MSW landfill and OP-MSW compost has the highest EC (12.6 – 32.46 $dS.m^{-1}$) as compared to the animal waste CL (2.6 – 4.05 $dS.m^{-1}$) and green waste CL (4.11 – 5.05 $dS.m^{-1}$). High EC indicates a high level of soluble salt content in the CL that can cause negative effects on plant growth and yield (Chan et al., 2016). Soluble salts produced are due to the degradation of complex organic matter.

Table 1: List of parameters for CL

Source of CL	Age of CL	Physical Characteristics			Macronutrient (mg/L)			Micronutrient (mg/L)					REF
		COD (mg/L)	pH	EC (dSm^{-1})	N	P	K	Cu	Ni	Pb	Zn	Fe	
						MSW							
Untreated MSW landfill	>10 y	-	8.7	32.5	2,438	46	721	0.54	0.25	6.8	4.7	56	(a)
		-	7.1	15.7	-	-	4,100	12	1.42	6.8	181	-	(b)
		987 – 1,041	8.9 – 9.1	-	-	-	-	-	-	-	-	-	(c)
OP - MSW compost-ing plant	30 d	-	8.0	12.6	-	-	320	0.04	-	-	0.06	0.35	(d)
	7 d	105,330	4.9	28.9	-	-	-	-	-	-	-		(e)
	Fresh	65,000	3.8 – 6.3		-	-	-	0.11 – 0.49	0 – 1.19	0.06– 0.95	1.7– 34.5	101– 421	(f)
	Fresh	15,188	6.98	-	630	-	640	-	0.05	0.02	0.5	-	(g)
	-	-	5.15	13.05	1,038	67	2,546	-	-	-	-	-	(h)
						Animal waste							
Cattle manure	Fresh	-	8.4	2.80	490	-	-	2.14	-	-	3.24	131	(i)
	Fresh	100,000	7.4	-	-	-	-	-	-	-	-		(j)
Poultry manure	Fresh	6,542	-	3.84	380	290	690	10.0 ± 0.9	32.6 ± 0.3	30.1 ± 15.7	1.01 ± 0.02	0.68 ± 0.01	(k)
Cow manure	60 d	-	7.8	2.6	-	170		-	-	-	-		(l)
	72 d	-	6.0	-	900	500	600	-	-	-	-		(m)
Pig manure	Fresh	-	8.4	4.05	-	-	-	0.38	-	-	1.72	40	(n)
						Green waste							
Garden and yard waste	-	1,152	8.79	5.05	-	-	-	-	-	-	-		(o)
	85 d	-	7.1	-	700	400	500	-	-	-	-		(p)
	2 d	11,600	5.1	-	-	-	-	-	-	-	-		(q)
	-	804	8.59	4.11	-	-	-	-	-	-	-		(r)
	-	-	-	-	400	100	1,000	5.89	-	-	2.47	40	(s)

REF= Reference. [(a)]Singh et al. (2017), [(b)]Asadi et al. (2011), [(c)]Peng et al. (2018), [(d)]Jarecki et al. (2012), [(e)]Bakhshoodeh et al. (2017), [(f)]Liu et al. (2010), [(g)]Romero et al. (2013), [(h)]Singh et al. (2010), [(i)]Cáceres et al. (2015), [(j)]Neshat et al. (2017), [(k)]Markou et al. (2016), [(l)]Gutiérrez-Miceli et al. (2008), [(m)]Tejada et al. (2008), [(n)]Cáceres et al. (2015), [(o)]Tyrrel et al. (2008), [(p)]Tejada et al. (2008), [(q)]Brown et al. (2013), [(r)]Tyrrel et al. (2008), [(s)]Ávila-Juárez et al. (2015)

CL from MSW has the highest nutrient range (630 – 2,438 mg/L) and the highest K content (640 – 4,100 mg/L). Animal and green waste CL reported a high P composition range (100 – 500 mg/L) compared to the MSW CL. CL from biowaste also contains micronutrient such as magnesium (Mg), calcium (Ca) and sodium (Na) (Jarecki et al., 2005). High level of trace elements (TE) in CL would be considered as heavy metals. From the review, the TE in MSW (Cu = 0.04 – 12 mg/L, Ni = 0.05 – 1.42 mg/L, Pb = 0.02 – 6.8 mg/L, Zn = 0.06 – 181 mg/L, Fe = 0.35 – 421 mg/L) and animal waste (Cu = 0.38-2.14 mg/L, Ni = 32.6 ± 0.3 mg/L, Pb = 30.1 ± 15.7 mg/L, Zn = 1.01-3.24 mg/L, Fe = 0.68-131 mg/L) have exceeded the maximum concentrations of TE recommended for water irrigation set by the Food and Agriculture Organization of the United Nations (FAO) (Cu = 0.2 mg/L, Ni = 0.2 mg/L, Pb = 5.0 mg/L, Zn = 2.0 mg/L, Fe = 5.0 mg/L) (Jeong et al., 2016). Apart from the need for TE removal treatment, dilution is recommended to reduce the TE concentration in the CL, however, dilution will significantly compromise the concentration of macronutrients. Some TEs were considered hazardous even at a very low concentration such as Hg.

The information from Table 1 is useful for users to estimate the dilution rate needed to apply different CL on the plant. Singh et al. (2010) and Tejada et al. (2008) applied about 100 to 500 dilution factors (2 – 10 mL CL in 1 L water), using green waste CL on strawberry and animal waste CL on tomato. Due to the higher range of nutrients in MSW CL, the dilution rate would be higher, i.e. 500 to 1,000 dilution factors (1 – 20 mL of CL per L of water). Over-dilution may result in P deficiency since MSW CL has a low P nutrient compared to animal and green waste. However, CL from mixed or unsorted MSW is not recommended as liquid fertiliser and forbidden in the EU countries for application to agriculture land. For the application of CL on larger plants or in the soil, a lower dilution rate is estimated as larger plants demands for higher nutrients and application in the soil is subjected to leaching by rainwater.

3.2 Nutrient content of the plants treated with CL

CL can be applied to the plant by spraying on the plant leaves as foliar fertiliser or applied to the soil directly. CL can be absorbed into the soil, giving direct nutrient access to the plant compared to solid compost. Table 2 shows the nutrient uptake by different plants treated with CL from different biowaste.

Table 2: Nutrient uptake by different plants applied with CL from different biowaste

Type of plants	Species of plant	N uptake (g/kg)			P uptake (g/kg)			K uptake (g/kg)			References
		Soil /root	Leave/ shoot	Fruits /grain	Soil /root	Leave/ shoot	Fruits /grain	Soil /root	Leave/ shoot	Fruits /grain	
						MSW					
Large plants	Black Locust	-	42.4	-	-	2.8	-	-	15.7	-	Jarecki et al. (2012)
	Paddy	-	28.7	28.2	-	3.1	4	-	20.1	5	Carlos et al. (2017)
	Wheat	-	22.7	-	-	3.5	-	-	5	-	Kuwano et al. (2017)
						Animal waste					
Large plants	Corn	14.1	-	10.7	18.5	-	1.9	95	-	9	Matsi et al. (2015)
Small plants	Strawberry	-	6	2.3	-	9.3	4.9	-	24.5	12.3	Singh et al. (2010)
						Green waste					
Small plants	Tomatoes	41	38	-	7	6	-	15	45	41	Jarecki et al. (2005)
	Marigold	30	25	-	6	7	-	68	67	-	Jarecki et al. (2005)
	Strawberry	-	6.4	2.4	-	10.1	5.2	-	25.7	12	Singh et al. (2010)

Referring to Table 2, all three crops treated with MSW CL recorded a higher N composition in the leaves, shoots and grains area (22.7 – 42.4 %) as compared to P and K. MSW CL has high nutrient contents (N = 630 – 2,438 mg/L, P = 46 – 67 mg/L, K = 320 – 4,100 mg/L). Small plants such as tomato and Marigold plant treated with green waste CL contains high N content in the leaves and shoot (25 – 38 g/kg) compared to other parts of the plant, despite moderate N composition (N = 400 – 700 mg/L) in the green waste CL. High N content in the leaves might be due to high chlorophyll content in the leaves. Jarecki et al. (2012) reported a significant positive correlation between foliar N and chlorophyll content in the plant. More than 50 % of N in leaves are used for photosynthesis, and N availability is integral for carbon fixation (Behie and Bidochka, 2014). Therefore, CL should be sprayed directly to the leaves and grains for all plants for direct N absorb.

P is high in soil and root area for both the large and small plants following the application of animal and green waste CL. P in the form of orthophosphate (PO_4^{3-}) are abundant in soil and can be absorbed directly by plant roots or by roots colonized by mycorrhizal fungi (Behie and Bidochka, 2014). This indicates that CL can be applied to soil for direct P uptake. Small plants (Strawberries, marigold and tomato) reported a higher P content in the leaves/shoots and fruits area (20 – 40%) compared to large plants.

K concentration is high in soil and roots area in both the small and large plants. This is due to the presence of water-soluble K (in soil water) and exchangeable K (located at clay particles, an active portion of the soil where chemical reactions such as K exchange occur) (Yadav and Sidhu, 2016). Plants readily absorb water-soluble K. Application of CL in the soil can increase the water-soluble K content. Smaller plants have a higher K content in the leaves, shoots and fruits area (5 – 20 %) compared to large plants such as paddy and wheat.

Different plants have different nutrient uptake rate in different parts of the plant. Most of the plants have a high N content in the leaves area. Smaller plants have a high P and K content in the shoot, leaves and fruits compared to larger plants. Strawberries treated with CL from different biowaste contain a similar P and K content in the fruits/grain and soil/root area. These results indicated that the same plants will have a similar range of nutrient uptake (P: leaves area (10.1 – 9.3 g/kg) and fruits area (4.9 – 5.2 g/kg); K: soil/root (4.9 – 5.6 g/kg) and fruits/grain (24.5 – 26.4 g/kg) although CL at different level of nutrients are applied. Application of an adequate range of CL nutrients is essential from the agronomic point of view.

4. Conclusion

The physical and nutrient composition of the CL varied depending on the biowaste source. Fresh MSW CL contains the highest COD range, which is 1 – 10 % higher than CL from different biowaste due to the high organic carbon content. Fresh (2 d) MSW CL and green waste have an acidic pH (3 – 5) compared to older CL due to the high concentration of VFA from the degradation of organic carbon. Treatment of CL is needed to reduce the initial COD level and neutralise the pH. The nutrient ranges of CL from different biowaste are summarised in this study to guide the specific dilution rate for the application of CL on plants. CL from green and animal biowaste required 100 – 500 times dilution and CL from MSW biowaste required 500 – 1,000 times dilution. Nutrient uptake by the plant varied based on the type of plant. In most of the plants, 50 % of N is located in the leaves area and more than 60 % of the P and K are located in the soil and root area. This indicates that plants would absorb the readily available N through the leaves and P and K through the root. CL should be applied through soil (fertigation) and spray directly at leaves for direct nutrient absorption. However, the nutrient uptake rate for a specific plant is rather consistent regardless of the nutrient range of CL applied. This highlights the need for applying CL at the right nutrient range for specific plants to fulfil the agronomic goal. Nutrient uptake rate and the nutrient content in the plant provide valuable information for users to estimate the dilution rate required for the application of CL. This review is conducted to relate the nutrient range in CL from different biowaste, and the dilution range required for further application on plants. Limitation remained to generalise the nutrients range for CL generated from a specific type of biowaste. In future research, on-going sampling to characterise the physical and nutrient of CL from a large range of biowaste should be conducted to minimise the standard of deviation on the nutrient range. These data are valuable to commercialise and utilise CL as a renewable nutrient source to fulfil the nutrient demand of crop while minimising pollution due to the run-off of leachate to the underground water and the ecosystem.

Acknowledgement

The authors acknowledge research grants from the Ministry of Higher Education (MOHE) Malaysia with grant no. 7301.4B145 and 2546.15H25; and from Universiti Teknologi Malaysia with the grant no. 2546.14H65 and 2501.10H28. The research has been supported by the project Sustainable Process Integration Laboratory – SPIL, No. CZ.02.1.01/0.0/0.0/15_003/0000456, funded by European Research Development Fund, Czech Republic Operational Programme Research, Development and Education, Priority 1: Strengthening capacity for quality research under a collaboration agreement with Universiti Teknologi Malaysia, Johor Bahru, Malaysia.

References

Asadi A., Huat B. B. K., Moayedi H., Shariatmadari N., Parsaie A., 2011, Changes of hydraulic conductivity of silty clayey sand soil under the effects of municipal solid waste leachate. International Journal of the Physical Sciences, 6(12), 2869-2874.

Ávila-Juárez L., Rodríguez González A., Rodríguez Piña N., Guevara González R., Torres Pacheco I., Ocampo Velázquez R., Moustapha B., 2015, Vermicompost leachate as a supplement to increase tomato fruit quality. Journal of Soil Science and Plant Nutrition, 15, 46–59.

Bakhshoodeh R., Alavi N., Paydary P., 2017, Composting plant leachate treatment by a pilot-scale, three-stage, horizontal flow constructed wetland in central Iran. Environmental Science and Pollution Research, 24(30), 23803-23814.

Behie S W., Bidochka M J., 2014, Nutrient transfer in plant-fungal symbioses, Nutrient transfer in plant–fungal symbioses, Trends in plant science, 19(11), 734-740.

Brown K., Ghoshdastidar A. J., Hanmore J., Frazee J., Tong A. Z., 2013, Membrane bioreactor technology: A novel approach to the treatment of compost leachate. Waste Management, 33(11), 2188–2194.

Cáceres R., Magrí A., Marfà O., 2015, Nitrification of leachates from manure composting under field conditions and their use in horticulture. Waste Management, 44, 72–81.

Carlos F. S., Giovanella P., Bavaresco J., Borges C. de S., Camargo F. A. de O., 2016, A Comparison of Microbial Bioaugmentation and Biostimulation for Hexavalent Chromium Removal from Wastewater. Water, Air, and Soil Pollution, 227(6), 175.

Carlos F. S., Marafon A. J., Andreazza R., Anghinoni I., Tedesco M. J., de Oliveira Camargo F. A., 2015, Electrochemical changes and nutrient dynamics in the solution of soil with rice irrigated with treated industrial leachate. Revista Brasileira De Ciencia Do Solo, 39(2), 466-474.

Chan M. T., Selvam A., Wong J. W. C., 2016, Reducing nitrogen loss and salinity during “struvite” food waste composting by zeolite amendment. Bioresource Technology, 200, 838–844.

Eigenbrod C., Gruda N., 2015, Urban vegetable for food security in cities. A review. Agronomy for Sustainable Development, 35(2), 483–498.

Foo K. Y., Hameed B. H., 2009, An overview of landfill leachate treatment via activated carbon adsorption process. Journal of Hazardous Materials, 171(1-3), 54-60.

Gutiérrez-Miceli F. A., García-Gómez R. C., Rincón Rosales R., Abud-Archila M., María Angela O. L., Cruz, M. J. G., Dendooven L., 2008, Formulation of a liquid fertilizer for sorghum (Sorghum bicolor (L.) Moench) using vermicompost leachate. Bioresource Technology, 99(14), 6174–6180.

Hashemi H., Khodabakhshi A., 2016, Complete treatment of compost leachate using integrated biological and membrane filtration processes. Iranian Journal of Chemistry and Chemical Engineering, 35(4), 81–87.

Jarecki M. K., Chong C., Voroney R. P., 2005, Evaluation of compost leachates for plant growth in hydroponic culture. Journal of Plant Nutrition, 28(4), 651–667.

Jarecki M. K., Voroney R. P., Chong C., 2012, Evaluation of compost leachate for growing nursery trees on a waste-rehabilitated field site. Compost Science and Utilization, 20(3), 171–180.

Jeong H., Kim H., Jang T., 2016, Irrigation water quality standards for indirect wastewater reuse in agriculture: a contribution toward sustainable wastewater reuse in South Korea. Water, 8(4), 169.

Kuwano B. H., Nogueira M. A., Santos C. A., Fagotti D. S. L., Santos M. B., Lescano L. E. A. M., Andrade D. S., Barbosa G. M. C., Tavares-Filho J., 2017, Application of landfill leachate improves wheat nutrition and yield but has minor effects on soil properties. Journal of Environment Quality, 46(1), 153-159.

Liu J., Zhong J., Wang Y., Liu Q., Qian G., Zhong L., Guo R., Zhang P., Xu Z. P., 2010, Effective bio-treatment of fresh leachate from pretreated municipal solid waste in an expanded granular sludge bed bioreactor. Bioresource Technology, 101(5), 1447-1452

Matsi T., Lithourgidis A. S., Barbayiannis N., 2015, Effect of liquid cattle manure on soil chemical properties and corn growth in northern greece. Experimental Agriculture, 51(3), 435-450.

Mokhtarani N., Bayatfard A., Mokhtarani B., 2012, Full scale performance of compost's leachate treatment by biological anaerobic reactors. Waste Management and Research, 30(5), 524–529.

Markou G., Iconomou D., Muylaert, K., 2016, Applying raw poultry litter leachate for the cultivation of Arthrospira platensis and Chlorella vulgaris. Algal Research, 13, 79–84.

Mougeot L., 2000, Urban agriculture: definitions, presence, potentials and risks, Growing cities, growing foods: urban agriculture on the policy agenda, 31, 1–42.

Neshat S. A., Mohammadi M., Najafpour G. D., 2017, Photosynthesis assisted anaerobic digestion of cattle manure leachate in a hybrid bioreactor: An integrated system for enhanced wastewater treatment and methane production. Chemical Engineering Journal, 330, 616-624.

Peng W., Pivato A., Lavagnolo M. C., Raga R., 2018, Digestate application in landfill bioreactors to remove nitrogen of old landfill leachate. Waste Management, 74, 335-346.

Romero C., Ramos P., Costa C., Carmen Márquez M., 2013, Raw and digested municipal waste compost leachate as potential fertilizer: Comparison with a commercial fertilizer. Journal of Cleaner Production, 59, 73–78.

Singh R., Gupta R. K., Patil R. T., Sharma R. R., Asrey R., Kumar A., Jangra, K. K., 2010, Sequential foliar application of vermicompost leachates improves marketable fruit yield and quality of strawberry (Fragaria ananassa Duch.). Scientia Horticulturae, 124(1), 34–39.

Singh S., Janardhana Raju N., Rama Krishna C., 2017, Assessment of the effect of landfill leachate irrigation of different doses on wheat plant growth and harvest index: A laboratory simulation study. Environmental Nanotechnology, Monitoring and Management, 8, 150–156.

Singh S., Raju N.J., Gossel W., Wycisk P., 2016, Assessment of pollution potential of leachate from the municipal solid waste disposal site and its impact on groundwater quality, Varanasi environs, India. Arabian Journal of Geosciences, 9, 131.

Tejada M., Gonzalez J. L., Hernandez M. T., Garcia C., 2008, Agricultural use of leachates obtained from two different vermicomposting processes. Bioresource Technology, 99(14), 6228–6232.

Tyrrel S. F., Seymour I., Harris J. A., 2008, Bioremediation of leachate from a green waste composting facility using waste-derived filter media. Bioresource Technology, 99(16), 7657-7664

Yadav B. K., Sidhu A. S., 2016, Dynamics of potassium and their bioavailability for plant nutrition. Potassium Solubilizing Microorganisms for Sustainable Agriculture, 14, 187-201.

Yang F., Li Y., Han Y., Qian W., Li G., Luo W., 2019, Performance of mature compost to control gaseous emissions in kitchen waste composting, Science of the Total Environment, 657, 262–269.