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Effects of Leachate Irrigation on Landfill Vegetation and Cover Soil Qualities

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Abstract: Vegetation on cover soils, as recommended to protect cover soil from erosion, can be affected by leachate re-circulation employed for treating leachate or accelerating gas production in landfill. In this study, three tropical grasses were investigated for their tolerance to landfill leachate, The potted grasses in pots were irrigated with leachate at different concentrations. It appeared that all plant species were severely damaged when high concentration of leachate was applied. High electrical conductivity in leachate was not the major factor causing plant damage but high organic contents did affect their survival. Nevertheless, the irrigation of leachate at optimum concentration stimulated the growths of some plant species. The lysimeter study confirmed that two landfill gas exposed plants irrigated with leachate at a concentration of 1,770mgCOD.L^{-1} and hydraulic application rate of 0.57cm.d^{-1} were growing faster than the plants irrigated with rainwater. Improvement of soil qualities from additional nutrients gained from leachate was observed. This study suggests that the selection of appropriate grass species and provision of optimum organic loading rate should be considered in order to prevent the damage of landfill vegetation when leachate irrigation is practiced in the landfill.

Keywords: Leachate irrigation, leachate re-circulation, landfill vegetation, landfill cover soil

Introduction

Landfilling is the conventional method for solid waste disposal especially when large land area is available. Compared to open-dumping method, landfilling could limit environmental problems such as odorous smell, infectious vectors, leachate pollution etc. Moreover, landfill gas commonly generates in landfill can also be used as renewable energy. Many researchers have proposed several techniques to increase gas production rate in landfill. Leachate re-circulation is one of the recommended methods for the enhancement of landfill gas production. Since it could recycle available nutrients and maintained moisture content required for anaerobic biodegradation.Beside, this operation is advantageous in reducing leachate concentration [1]. However, leachate re-circulation can also provide negative impacts. Although irrigation of leachate can maintain soil moisture necessarily for vegetation, high salinity in leachate can also damage the vegetation. Generally, the most important water quality parameter for irrigation is the salt concentration , commonly measured as electrical conductivity (EC) [7]. On this point of view, planting of salt tolerant-plant on the landfill and provision of leachate at optimum concentration should be considered for the achievement of sustainable irrigation in landfill operation. Thus, this study was focused on the effects of leachate concentrations on different species of tropical grasses. The studies were conducted through pot and lysimeter experiments. Beside, soil property changes during leachate irrigation, i.e. soil EC and pH, and soil respiration, were also studied via another set of batch experiments.

Materials and Methods

Experiments of Effects of Leachate on Vegetation

Preparation of grasses species and planting methods

Three species of grasses were selected in the study due to their properties of salttolerances [8]. They were Penniselum purpureum, Cynodon plecloslachyrus, and Sporobolus virginicus. Their main characteristics are adaptability to most soil types, grown well on fertile, sandy, and silt soils. They can survive in wide ranges of soil conditions especially in acid and saline soils (EC>3.2 $dS.m^{-1}$; [7]). For pot-experiment, each species had grown in triplicate pots containing 1.2-kg sandy clay loam (61.4% sand, 10.6 silt and 28% clay). The triplicate pots (each of 15-cmxI5-cm) were irrigated with different concentration of leachate. The soil chemical properties are illustrated in Table 1. At the beginning of experiment, shoot of grass leaves were cut-off to obtain an initial height of 10-cm. Then all pots were irrigated with rainwater every day during the first two weeks to prepare healthy grasses before applying leachate. For lysimeter study, healthy grasses (c. placloslachyrus and S. virginicus) were planted in the lysimeters before being supplied with synthetic landfill gas (60% CH4 and 40% CO2)

Leachate preparation and methods of leachate irrigalioll

Pot experiment: Leachate was obtained from municipal solid waste landfill Iysimeters. The characteristics of leachate are shown in Table I. Different concentrations of leachate were prepared to obtain10,20,50,100% of leachate in rainwater. This leachate had EC concentrations of 1.05, 2.06, 4.00, and 8.18 $dS.m^{-1}$ and COD concentrations of 1770, 3540, 8850 and 17700$mg.L^{-1}$ respectively. Leachate of 50-mL at each concentration was applied to the pot once a week for 4 months; equivalent to a hydraulic application rate (HAR) of 0.57 $cm.d^{-1}$. For control experiment, rainwater was used instead of leachate.

Lysimeter experiment*:* Simulation of actual condition in landfill was conducted in this experiment. Four lysimeters were set-up to examine different operating conditions of landfill final cover soils. The Iysimeters were made of 15-cm cylindal acrylicmaterial and filled with sandy loam soils (70%sand, 20%clay, 10% silt) of 60 cm. depth. The chemical properties of soil are shown in Table 1 and their bulk densities were 1,450 $kg.m^{-3}$. Based on the results of the pot-experiment, leachate tolerant plant..species i.e. C. *pleetostaehyrus,* and S. *virginieus,* were selected and used in the lysimeters. Same method employed in nursery phase of pot-experiment was used. Each plant species were examined under two conditions i.e. irrigation with 10% leachate (1,770 $mgCOD.L^{-1}$) and rainwater (control) with HAR of 0.57 $cm.d^{-1}$. Alllysimeters were fed with synthetic landfill gas (60%CH4 and 40%COz) at a flow rate of 3.91$mL.min^{-1}$). Another two Iysimeters with rainwater irrigation were conducted as control experiment. The growth of plant was recorded along the experimental period.

Experiments of Effects of Leachate on Soil Quality/Soil Respiration

Soil quality*:* Accumulations of EC and organic carbon (OC) contents in soils due to leachate irrigation were investigated in this experiment. Forty pots with 50-g of sandy clay loam soils each were prepared. The same soil and leachate with pot experiment were used. About 2 mL of leachate of different concentration was applied into testing pot every day for eight weeks. This is equivalent to the same volumetric loading rate of leachate as in the pot-experiment (41.67 $mL.kg^{-1}$ $soil.d^{-1}$) in which COD loading rates were varied at 0.074, 0.147, 0.367, 0.74 mg COD.g $soil^{-1}.d^{-1}$ depending on leachate concentration. Every week, two pots were examined for the accumulation of EC and OC contents in the soils.

Table 1 Characteristics of soil and leachate used in the experiments

Composite soil characteristics	Pot experiment	Lysimeter experiment	Raw leachate characteristics	
pH (Soil:H_2O = 1:2)	4.4	8.35	PH	5.7-6
EC (Soil:H_2O = 1:2)	0.159	0.03	BOD, $mg.L^{-1}$	13,000-16,500
Moisture content, %	4	-	COD, $mg.L^{-1}$	16,000-19,000
Organic matters, %	1.91	0.092	TKN, $mg.L^{-1}$	400-800
Available P, $mg.kg^{-1}$	9	26	NH_3-N, $mg.L^{-1}$	300-500
Available K,$mg.kg^{-1}$	41.0	104	NO_3-N, $mg.L^{-1}$	3-8
NH_3-N, $mg.kg^{-1}$	22.4	5.63	Orthophosphate, $mg.L^{-1}$	60-80
NO_3-N, $mg.kg^{-1}$	5.6	0.07	Chloride, $mg.L^{-1}$	700-1,500
CEC, $cmol_c.kg^{-1}$	11.7	4.2	EC, $dS.m^{-1}$	8.0-8.3

Soil Respiration*:* This experiment was set up to determine the effects of leachate concentration on soil respiration in term of oxygen uptake rate (OUR). Ten grams of sandy clay loam soils were placed into 118-ml serum bottles. Different leachate concentrations were prepared by diluting concentrated leachate with distilled water. A 0.5-mL of leachate at each concentration was transferred into duplicate bottles to obtain COD loading of 0.05, 0.07, 0.18, 0.36, 0.76,1.34 and 1.92 $mg.g^{-1}$ soil. Then, the bottles were closed with the alumiimm-silicone caps. A headspace gas in each bottle was analyzed for its composition using a gas chromatograph (GC6890, Agilent; TCD*,* carrier gas: helium 65 ml/min; packing materials: CRT1, Alltech in stainless steel column).

Results

Effects of Leachate on Vegetation

Pot Experiment: The effect of leachate concentration on plant growth was investigated in this experiment. Fig.1 shows the changes in heights of *P. purpureum* during the applications of leachate at different concentrations. The results indicate that tropical grasses could be grown well when being applied with rainwater and 10% leachate during 15 weeks of experimental period. At higher concentrations of applied leachate, the grasses died after 13 weeks at 20% and 7 week at 50-100% leachate concentrations respectively. When comparing the growth rates of grasses between rainwater and 10% leachate irrigation cases, it was found that irrigation of 10% leachate could stimulate the growth of *P. purpureum* especially after 7 week of experimental period. This could be a result fiom additional plant nutrients available in leachate. The same growth pattern was found in case of C. *plectostachyus* (Fig. 2). However, different result in case of S. *virginicus* was obtained. S. *virginicus* could be survived and stimulated when 20% leachate (EC of 2 $dS.m^{-1}$ or COD of 3,500 $mg.L^{-1}$) was applied indicating that S. *virginicus* was the most leachate tolerant grass in this study (Fig.3). The results suggest that although all three plant were those of salt-tolerant species, they could be severely damaged when exposing to high concentrated leachate(EC $\geq$ 4.00 $dS.m^{-1}$, organic matters $\geq$ 8,850 mg $COD.L^{-1}$) while irrigation with an optimum leachate concentration can stimulate growth of some species.

Lysimeter Experiment: The growths of C. *plectostachyus* and S. *virginicus* in six lysimeters (3 conditions) were observed during 70 days of operational period (Table 2). The results show that the growth of S. *virginicus* and C. *plectostachyus* in the Iysimeters operated under typical condition of landfill (exposed to landfill gas and rainwater) was limited. Nevertheless, opposite result was found in the case of 10% leachate concentration. The plants were found having higher growth rates even when compared with natural growing condition (without landfill gas). It suggests that vegetation exposed to landfill gas could be grown when optimal leachate concentration was provided.

Experiments of Effects of Leachate on Soil Properties/Soil Respiration

Effect of leachate on soil qualities: Because normally plants are normally sensitive to soil pH, EC and OC concentrations, accumulation of these pollutants in the soils was investigated in this experiment. Fig. 4 shows changes of soil EC during 8 weeks of experiment. It shows that diluted leachate in a range of 0 to 50% (0-4 $dS.m^{-1}$) had little effects on soil EC, while concentrated leachate (8 $dS.m^{-1}$) sharply increased soil EC after six weeks ofleachate spiking.

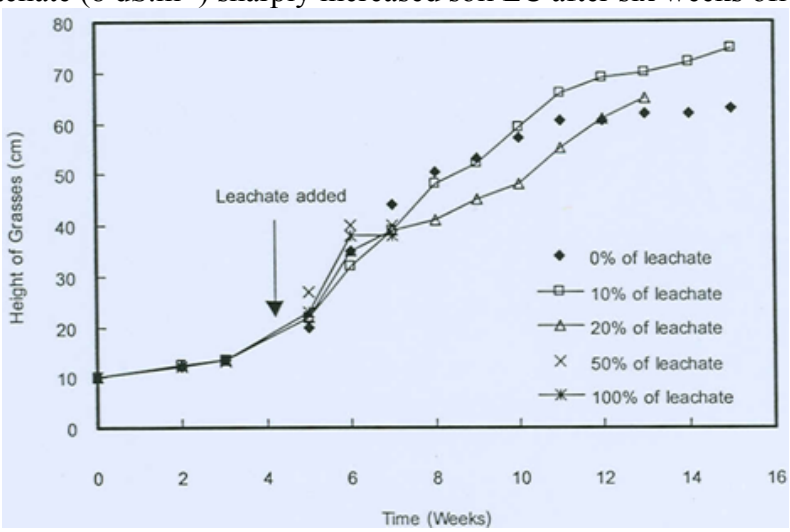

Fig.1 Changes of *P. purpureum* height during experimental period when irrigated with leachate at different concentrations. *Note:* Discontinued plots were used after plant death

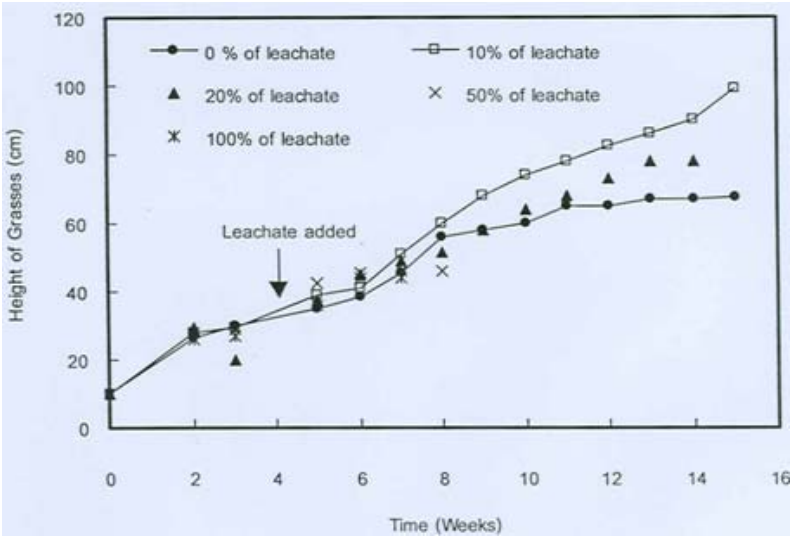

Fig.2 Changes of C. *plectostachyus* height during experimental period when irrigated with leachate at different concentrations. *Note:* Discontinued plots were used after plant death.

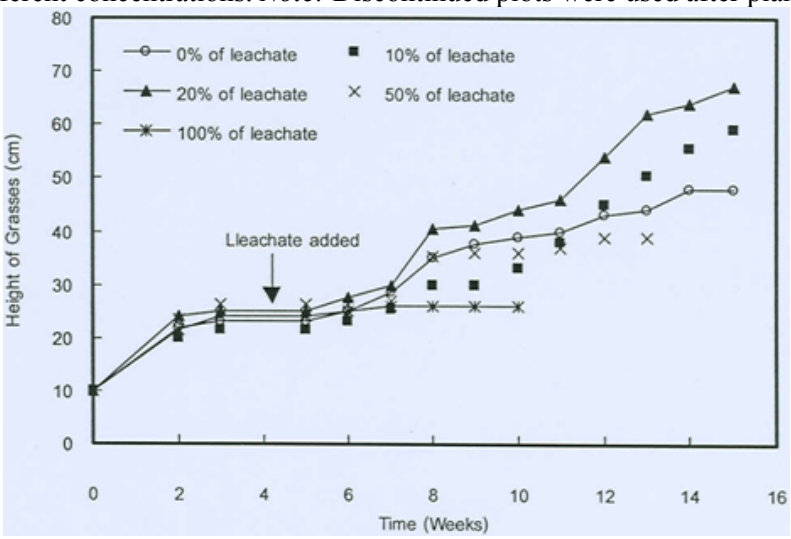

Fig.3 Changes of S. *virginicus* height during experimental period when irrigated with leachate at different concentrations. *Note:* Discontinued plots were used after plant death.

Table 2 Average growths of *S.virginicus* and *C. plectostachyus* in soil lysimeters operated under various conditions after 70 day of operation

Parameters/ conditions	*S.virginicus*			*C. plectostachyus*		
	14th day*	70th day	Differences	14th day*	70th day	Differences
Plant height, cm						
Control (RW)	25.0	57.0	+32.0	25.0	60.0	+35.0
RW + LFG	27.2	52.0	+24.8	25.0	53.0	+28.0
LC + LFG	28.5	65.0	+36.5	27.0	70.2	+43.2
Amount of leave						
Control (RW)	32	98	+66	9	28	+19
RW + LFG	35	76	+41	12	49	+37
LC + LFG	41	118	+77	10	56	+46
Amount of plants						
Control (RW)	6	10	+4	7	11	+4
RW + LFG	6	11	+5	7	8	+1
LC + LFG	9	14	+5	7	11	+4
Leave width, cm						
Control (RW)	0.25	0.30	+0.05	0.25	0.50	+0.25
RW + LFG	0.25	0.30	+0.05	0.30	0.50	+0.20
LC + LFG	0.25	0.35	+0.10	0.20	0.50	+0.30

Note: * the last day of nursery phase, RW: Rainwater; LC: Leachate, LFG: Landfill gas

The measurement of soil EC in pot experiment was summarized in Table 3. It was found that *P. purpureum* and C. *plectostachyus* died after 2nd week of 50 and 100% of leachate irrigation whenever soil EC were found in range of 1.6-1.8 $dS.m^{-1}$ For S. *virginicus,* EC content was found in a range between 1.9-2.4 $dS.m^{-1}$ after plant death. In term of OC content (Fig 5), obvious increase in OC contents of soils were found when being spiked with 50 and 100% of leachate. After 8th week of leachate irrigation, OC. contents increased from an initial of 0.1 % to a final of 1.3 and 1.5% when exposed to 50 and 100% leachate concentration, respectively. In the determination of soil pH (Fig. 6), it was found that soil pH was lowered when leachate concentrations increased. High reduction in pH was found especially in soil irrigated with concentrated leachate.

Effect of leachate on soil respiration: Fig. 7 shows the relationship between leachate addition (as COD loading rate, $mg.g^{-1}$ soil) and soil respiration (oxygen uptake rate; OUR, $mole.h^{-1}$). The results indicate that OUR in soils increased with an increase in COD loading. Rapidly increase in OUR was found when COD loading in excess of 0.36 mg COD.g $soil^{-1}$ was applied. A maximum OUR of about 20)umoles $O_2.h^{-1}$ (0.496 ml $O_2.h^{-1}$) was obtained in the soil spiked with leachate having COD loading of 1.92 $mg.g^{-1}$ soil. The result suggests that there were higher microbial activities in soil when being irrigated with concentrated leachate.

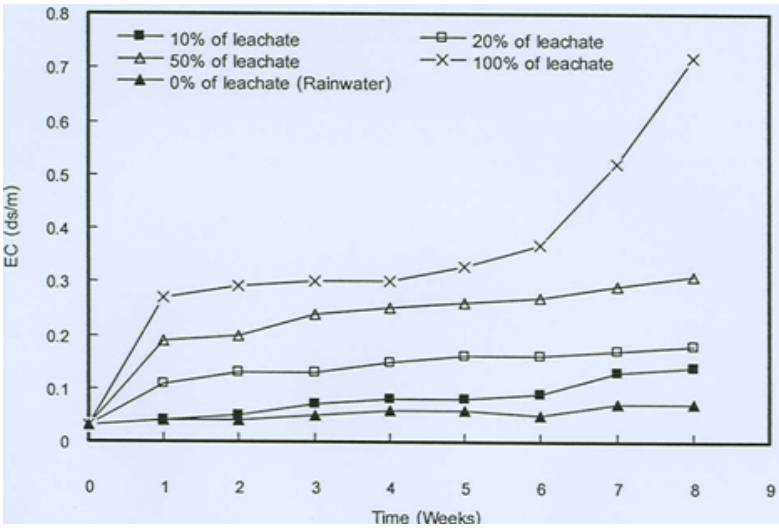

Fig.4 Changes of EC in soil when being spiked with leachate at different concentrations for eight weeks.

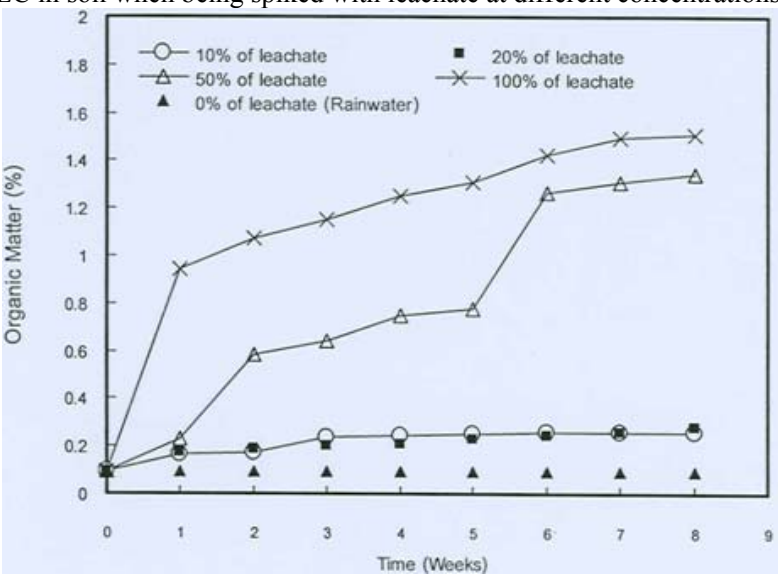

Fig.5 Changes of organic matter contents in soil when being spiked with leachate at different concentrations for eight weeks.

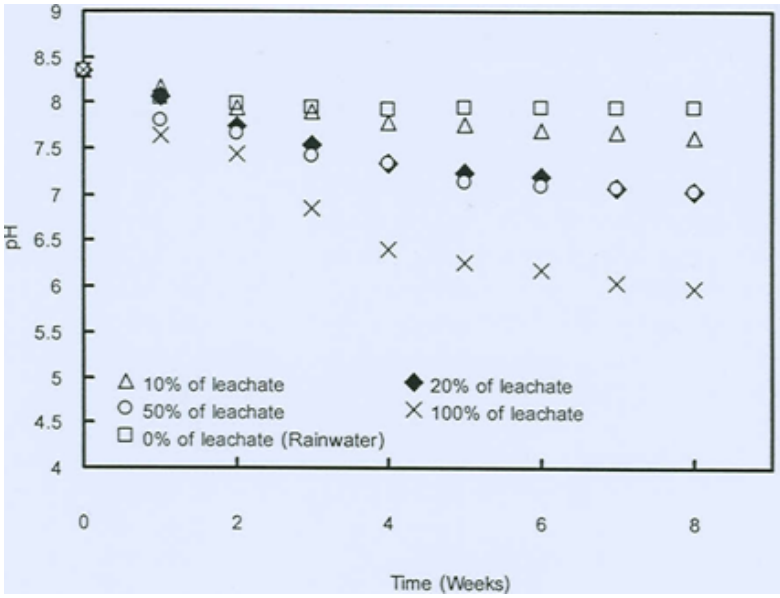

Fig. 6 Changes of soil pH when being spiked with leachate at different concentrations for eight weeks.

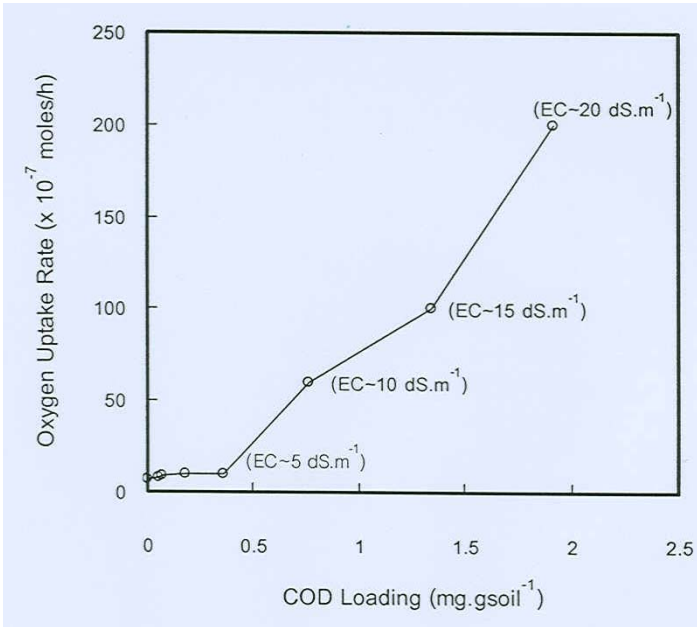

Fig.7 Oxygen uptake rate (OUR) in soils when being spiked with leachate at different concentrations.

Table 3 Soil EC after irrigated by leachate in batch experiments.

Plant Species	EC level in leachate, dS m^{-1} (Leachate dilution)				
	0.0 (0%)	1.05 (10%)	2.06 (20%)	4.00 (50%)	8.18 (100%)
P. purpureum *(Date of measurement)*	0.38 (12th wk)[1]	0.50 (12th wk)[1]	2.50 (7th wk)[2]	1.56 (1st wk)[2]	1.50 (1st wk)[2]
C. plectostachyus *(Date of measurement)*	0.40 (12th wk)[1]	0.60 (12th wk)[1]	1.29 (1st wk)[2]	1.64 (1st wk)[2]	1.78 (1st wk)[2]
S. Virginicus *(Date of measurement)*	0.38 (12th wk)[1]	0.54 (12th wk)[1]	1.86 (12th wk)[2]	2.44 (13th week)[2]	2.36 (10th wk)[2]

Note: 1: The plants survived at the date of measurement.
2: Measurement after plant death.

Discussions

High contents of EC, COD and nutrients in leachate could be the possible cause of plant damage when vegetated cover soil was irrigated with leachate. Whereas soil pH was not the key factor as all plants were grown in soil with the same pH of 4 as shown in Table 1. From pot experiment, the result suggests that EC and/or COD content could be the primary factors relating to plant damage. In generally, level of soluble salts (all soluble ions express as EC level) in soil solution can provide significant impact on plant growth due to the occurrence of nutrient imbalance. The growth of sensitive plants is normally restricted in soil with EC in a range of 0.8-1.2 $dS.m^{-1}$ whereas those of some tolerant plants are 1.6-3.2 $dS.m^{-1}$ [7]. In this study, the death of grasses appeared when concentrated leachate was applied even though the accumulation of salt (1.8-2.4 $dS.m^{-1}$) was not found up to the plant damage range. Therefore, soil salinity should not be the major factor affecting the plant death. The possible reason for grass death should then be the accumulation of organic matter and subsequent rapid increase in OUR of soils. This created a long oxygen-absence condition in soils. For normal plant, root respiration is the first process to be affected by oxygen deficiency and the oxygen demand of plant root can be found in a normal range of up to1,600 ml $O2.kg^{-1}$ fresh $roots.h^{-1}$ [4].This cause of plant death is known as asphyxia [3]. Maurice and Langerkvist (1997) reported that oxygen content down to 5-10% in cover soil could have negative effect on vegetation in landfill. Carbon dioxide more than 20% could also reduce photosynthesis and plant's respiration of some plants [3]. In landfill, asphyxia of vegetation can also be caused by an effect from landfill gas. Methane has not been reported to be phytotoxic, but it can lead to asphyxia [3] and subsequently in deficiencies in K, N, P, Ca and Mg [2, 5]. For healthy grasses found in pot and lysimeter experiments (10% leachate irrigation), an appropriate organic loading rate prevented oxygen-deficient condition while providing additional nutrients for plant growth.

Conclusions

In pot experiment, all three species could not be grown when exposed to high concentrated leachate irrigation (>8,850 mg $COD.L^{-1}$), whereas the irrigation of diluted leachate (1,770-3,540 $mgCOD^{-1}$) stimulated the growth for some plant species. Leachate salinity was not the important factor causing plant death but an increase in organic matter contents in soil resulted in oxygen deficiency due to microbial activities. In lysimeter study, landfill gas had negative impact on growth of S. *virgincus, and* C. *plecloslachyus.* However, they could be recovered and yielded highest growth rates in Iysimeter when irrigated with 1,770 mg $COD.L^{-1}$ leachate at HAR of $0.57cm.d^{-1}$. This study suggests that selection of appropriate plant species and provision of optimum leachate concentration for irrigation were crucial in order to sustain the vegetation on landfill cover soil.

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