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Jean-Claude Revel, Philippe Morard, Jean-René Bailly, H. Labbé, C. Berthout, et al.. Plants' use of leachate derived from municipal solid waste.. *Journal of Environmental Quality*, 1999, 28 (4), pp.1083-1089. <10.2134/jeq1999.00472425002800040004x>. <hal-03483965>

HAL Id: hal-03483965

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To link to this article : DOI :10.2134/jeq1999.00472425002800040004x
URL : <http://dx.doi.org/10.2134/jeq1999.00472425002800040004x>

To cite this version : Revel, Jean-Claude and Morard, Philippe and Bailly, Jean-René and Labbé, H. and Berthout, C. and Kaemmerer, Michel *Plants' use of leachate derived from municipal solid waste*. (1999) Journal of Environmental Quality, Vol. 28 (N° 4). pp. 1083-1089. ISSN 0047-2425

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Plants' Use of Leachate Derived from Municipal Solid Waste

J. C. Revel,* P. Morard, J. R. Bailly, H. Labbé, C. Berthout, and M. Kaemmerer

ABSTRACT

Leachate was collected from a watertight pit at a landfill center dealing mainly with household refuse and plant waste. This effluent was characterized by a moderate organic matter content, a pH slightly higher than neutral and strong electrical conductivity. This latter was due to the presence of chlorides, Na, K, and ammonium. The organic content could be divided into two fractions: Fraction A consisting of large molecules (5000 Da and above) and Fraction B of smaller (between 300 to 1000 Da), more acidic molecules. The presence of phenols (sinapic acid, acetosyringone, and pyrogallol) could be identified in the leachate as a whole. A biological treatment of this leachate, involving methanization followed by aerated lagooning, was set up on the site: this led to a reduction of nearly 60% in the organic content and almost total elimination of the ammonium. This treatment was not however sufficient to allow direct evacuation of the resulting effluent into the surface ground water. As heavy metals were absent from this effluent, the leachates from this landfill site could possibly be envisaged in the fertilization of soil-grown crops or for furrow irrigation-fertilization of tree plantations. The effect of irrigating soil-grown plants with a solution of leachate was examined using pots of ryegrass (*Lolium* sp.). Application of solutions containing dilutions of 1 to 400 mL L⁻¹ of this effluent had a highly favorable effect on plant growth. Toxicity phenomena were apparent above this concentration. The optimum effect on ryegrass growth, under the conditions of this trial, was obtained by watering each pot with 30 mL of a solution containing 400 mL L⁻¹ of leachate, every 2 d. This solution improved water and N nutrition in these plants.

IN FRANCE, household refuse is subjected to different treatments after collection: 38% are incinerated, 6% composted, 4% recycled, and 52% are emptied on to authorized garbage dumps. In this latter case, the refuse collection services are obliged by law to bury such refuse on commissioned landfill sites so as to minimize any harmful effects on neighboring populations and the environment. The refuse is tipped, on arrival, into vast pits that have been excavated in impermeable soil, and is immediately compacted. At the end of the filling process, which may last several months, the pit is covered with a layer of clay soil. Such pits are therefore watertight and their subsequent evolution takes place under anaerobic conditions. The rainwater that accumulates during filling, together with degradation of the compacted biological matter, leads to the production of hundreds of cubic meters of a black foul-smelling liquid described as municipal solid waste leachate. This liquid accumulates at the bottom of the pits. The law, since 1994, stipulates that no more than 50 cm may remain at the bottom of the pit.

The chemical composition of these municipal solid waste leachates is dependent on a large number of fac-

tors: the nature of the refuse, the method of storage and subsequent evolution (aerobic or anaerobic), humidity, pH, temperature, and age of the landfill site (Chian and Dewalle, 1976; Farquhar, 1989). These products contain very high concentrations of C compounds together with mineral elements. The organic load and the biodegradability diminish with time. "Young" leachates mainly contain volatile fatty acids (VFA) whereas "mature" leachates contain substances similar to humic acids (Chian, 1977; Harmsen, 1983; Lema et al. 1988; Reitzel et al., 1992; Edeline, 1993). The mineral fraction consists of cations (NH₄⁺, K⁺, Na⁺...) and anions (Cl⁻, carbonates...). Such leachates do not contain normally heavy metals (Labbé, 1996). In fact even if the household refuse contains such contaminants, the sulphates present in the waste, which are reduced to H₂S during anaerobiosis, precipitate any heavy metals into their insoluble sulphides.

As a result of their composition, the direct evacuation of these municipal solid waste leachates into the ground water would cause problems by upsetting the receiving medium and requiring expensive treatment. One possible solution could consist of spreading them on the soil as organo-mineral fertilizer, but first the absence of toxic micropollutants and the presence of a favorable effect on biomass production would have to be ensured. This was the object of the present study that was carried out using municipal solid waste leachates from a landfill unit in south-west France (Montech, Midi-Pyrénées Region). The effect of spreading such liquids on soil was tested in pot-grown Italian rye grass (*Lolium italicum* L.).

MATERIALS AND METHODS

Municipal Solid Waste Leachates

The landfill site at Montech is designed to receive 200 000 tons of waste annually. It consists of approximately 20 pits, each about 1 ha in area. Each pit is excavated to about 10 m depth in impermeable molasses and made watertight with a compacted layer of clay loam extracted from the top layer of subsoil (Fig. 1). Further tightness is ensured by a geomembrane consisting of lengths of high density polyethylene sealed together and itself protected by a geotextile. A special low point is prepared at the bottom of the pit for collection of the leachate. The refuse is compacted and buried so that the height above soil level does not exceed 10 m. As the pit is filled with refuse, pipes are installed that will serve to collect the biogases produced by fermentation and to pump out the leachates. When the pit is full, it is covered with a thick layer of clay and a high density polyethylene geomembrane.

The Montech landfill unit was started in 1988. Seven pits

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Abbreviations: VFA, volatile fatty acids; COD, chemical oxygen demand; BOD₅, biological oxygen demand over 5 days; TOC, total organic carbon.

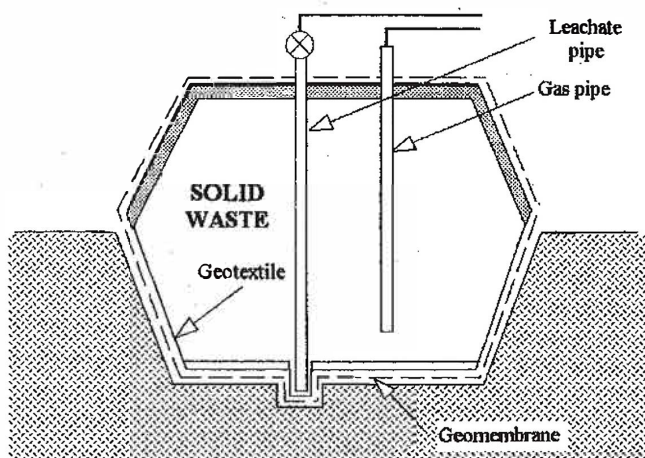


Fig. 1. General structure of a landfill pit for the reception of municipal solid waste.

have already been completed and the eighth is in the process of being filled.

The leachates used in the present study were obtained from the seventh pit that was in use from 12 Sept. 1994 until 31 Aug. 1995. This pit had been filled with 182 000 tons of refuse consisting of 61% of household refuse, 10% of plant waste, 2% of sludge, 5% of clinker and cumbersome objects, and 22% of ordinary industrial waste. The leachate used in these tests had been sampled on 26 Oct. 1995 when the pit was no longer in use. The samples were obtained via the pipe that served for leachate evacuation.

The leachates were subjected to the usual analyses for this type of product: pH and electrical conductivity; chemical oxygen demand (COD); concentration, expressed in mg L^{-1} , of oxygen equivalent to the amount of K dichromate required to oxidize a sample of leachate; biological oxygen demand over 5 days (BOD5) measured with the same oxidant; total organic carbon (TOC) obtained from the oxidation of C in acid medium by K dichromate (Vickery et al., 1995); mineral elements, (macro and oligoelements, heavy metals).

The organic fraction was examined more closely and the molecules separated according to molecular size (by gel permeation chromatography on Sephadex G25F dextrane gel (Pharmacia Biotech, Orsay, France). After extraction with isopropyl acetate, the phenol compounds were detected by HPLC (Lichrosorb RP18 column, (Lichrosorb, Merck, France), elution by a three-solvent gradient: distilled water-acetic acid-acetonitrile). This series of assays was completed by infrared analyses of the freeze-dried leachates.

Plant Growth Experiment

Tests to determine the effect of leachate on plant growth and water-mineral nutrition were performed in pot cultures with Italian ryegrass as the test plant.

The pots were 14 cm in diam. and filled with 1200 g of dry soil sieved through 2 mm mesh. The composition is given in Table 1. This soil contained a high concentration of active Ca and was chosen for its very low organic matter content so as to limit possible interference with the concentration of organic compounds in the leachate. The texture was well-balanced (loam-clay-sand) and the content of exchangeable bases and assimilable phosphates are usual for this type of soil.

Three hundred ryegrass seeds were sown per pot, as evenly as possible on the soil surface, then covered with 80 g of rinsed acid-washed sand that had been sieved through 1 mm mesh. The seeds were left to germinate at 18°C in the dark. After

Table 1. Soil specifications.

Physical characteristics	
Clay	25%
Silt loam	34%
Loam	10%
Sandy loam	21%
Sand	10%
Chemical characteristics	
pH water	8.2
pH KCl	7.5
Soluble limestone	6.80%
Total limestone	20%
Organic C	1.13%
N	0.14%
C/N	8.1
Organic matter	0.20%
Exchangeable bases	
	10%
Ca ²⁺	22.20 cmol kg ⁻¹
Mg ²⁺	5.30 cmol kg ⁻¹
K ⁺	0.16 cmol kg ⁻¹
Na ⁺	0.04 cmol kg ⁻¹
Available Fe	17 mg kg ⁻¹
Olsen P	320 mg kg ⁻¹

germination the pots were placed at random on a growth table in the glasshouse and their position altered once a week to limit any edge effects. The pots were placed into collecting tanks to reabsorb the surplus solution from watering: these effluents were absorbed by the roots of the ryegrass plants. The amount of water supplied every day was determined by assessing the difference between the weight of each pot and the weight to reach (1750 g) to maintain the soil at two-thirds of its retention capacity.

After 1 wk of growth a known volume (30 mL) of leachate solution was added every 2 d to the pots in each treatment. The additional amount of irrigation water required to maintain the soil water retention capacity was determined by weighing. The control pots received distilled water only. The first harvest was cut 3 wk after the first treatment and the second harvest 3 wk later. After this final cut the roots were washed with water to separate them from the soil and to remove any traces of this. The dry weights of the aerial parts obtained at each harvest, together with those of the roots, were determined by weighing. Each plant fraction was then analyzed. The total Kjeldahl N was determined after mineralization with sulphuric acid. The other mineral elements were determined after calcination at 550°C. The ashes were taken up in hydrochloric acid. Cations were analyzed by atomic absorption spectrometry (Perkin Elmer 373, France) and P by ceruleomolybdc reaction using a Unicam SP 1800 spectrophotometer (Unicam, Philips, France) set at 820 nm.

Two experiments were performed to determine the effects of solutions containing different concentrations of leachate on ryegrass growth, water consumption, and N absorption. The dilutions, actual quantities of leachate and the ammoniacal N applied to each treatment during growth are indicated in Table 2. There were two replicates of each treatment.

RESULTS AND DISCUSSION

Leachate Composition

The organic and mineral composition of the Montech municipal solid waste leachate is given in Table 3: these were "young" leachates obtained soon after closure of the seventh pit. This composition corresponds to the range of concentrations of the products normally encountered in this type of effluent (Chian and Dewalle,

Table 2. Dilutions and amount of leachates and ammonia N applied to each test.

	Dilution leachate	C contents	Leachate amount	Applied NH_4^+ N
	mL L ⁻¹	mg L ⁻¹	mL pot ⁻¹	mg
Test 1	0	0	0.0	0.0
	1.33	2.6	0.8	1.1
	2	4.0	1.1	1.7
	4	8.0	2.3	3.5
	10	20.0	5.7	8.7
	20	40.0	11.4	17.3
	40	80.0	22.8	34.7
	100	200	57.0	86.7
Test 2	200	400	114.0	173.3
	300	600	171.0	259.9
	400	800	228.0	346.6
	500	1000	285.0	433.2
	750	1500	427.5	649.8
	1000	2000	570.0	866.4

1976; Barber and Maris, 1984; Lema et al., 1988). It is however characterized by an average organic matter content, a pH slightly higher than neutral, a BOD5/COD ratio of 0.13 and strong electrical conductivity. This latter results from the high concentration of K, Na, and ammonium cations. The presence of a high content of ammoniacal N can be explained by the anaerobic decomposition of refuse containing more than 70% of household and green waste. Due to the pH these ions probably occur as salts (RCOONH_4) of macromolecules bearing humate-type organic acid functions. The analyses confirmed the very low heavy metal content and the

Table 3. Chemical composition of the Montech landfill leachate (November 1995).

Chemical characteristics†		
pH water	8.3	
Electrical conductivity	23.7 mS	
TOC	2300 mg L ⁻¹	
COD	3970 mg O ₂ L ⁻¹	
BOD5	500 mg O ₂ L ⁻¹	
Total N	1760 mg L ⁻¹	
Mineral composition		
Cations	mg L ⁻¹	mmol L ⁻¹
K ⁺	2200	56
Na ⁺	1920	83
NH ₄ ⁺	1520	84
Mg ²⁺	155	13
Ca ²⁺	60	3
Fe	7.8	0.3
Mn	0.22	
Zn	3.8	
Cu	0.08	
Σ cations		240
Anions	mg L ⁻¹	mmol L ⁻¹
Chlorides	2130	60
Phosphates	47	1
Nitrates	11	
Sulphates	4	
Σ anions		61
Heavy metals	mg L ⁻¹	
Cd	0.03	
Ni	0.14	
Pb	0.50	
Hg	0.01	
Cr	0.40	

† TOC, total organic carbon; COD, chemical oxygen demand; BOD5, biological oxygen demand over 5 days.

absence of sulphates corroborated their conversion into insoluble sulphides. The anion-cation balance was ensured by chlorides and probably by organic anions as well as the carbonates and bicarbonates derived from anaerobic fermentations (Delvin, 1990). It was not possible to determine the total alkalinity as the ionic equilibria was upset by the foam produced on removing the gases from the leachate at the pump outlet.

Different techniques were used to determine the organic content of the leachate. Firstly, dextrane gel chromatography was used to remove the molecules with weights <5000 Da (Fig. 2). Two groups of molecules were separated in this way: Fraction A, corresponding to tubes 59 to 99, consisted of the molecules eluted first and therefore of greatest size (5000 Da and above); Fraction B, obtained from tubes 145 to 169, was composed of smaller molecules (between 300 and 1000 Da).

Each fraction was then analyzed by infrared spectroscopy (Fig. 3): the resonance spectra were characteristic of certain organic functions. Fractions A and B both contained alcohol and phenol functions (3410–3426 cm⁻¹), asymmetric CH₂ groups (2925 cm⁻¹), quinone and amide C=O groups (1664 cm⁻¹), CH₂ and CH₃ groups (1399 cm⁻¹), and C–O–C ether functions (1043 cm⁻¹). The B fraction differed essentially in its absorption at 2553.7 cm⁻¹ that corresponded to a protonic H⁺ strongly bound to an hydroxyl group and signifying that these smaller molecules also were more acidic: the presence of a high density of carboxyl groups in the fraction containing the molecules of smallest size was confirmed by Chian, 1977. This B fraction also was characterized by the demonstration of two distinct absorption peaks at 825 and 699 cm⁻¹, which could be attributed to the CH groups of aromatic rings.

The presence of phenol functions and aromatic compounds in these fractions has been confirmed in the bibliography (Harmsen, 1983; Reitzel et al., 1992). A test to determine any free phenols was therefore applied to the complete leachate. After extraction with isopropyl acetate, the phenols were determined by HPLC (Ta-

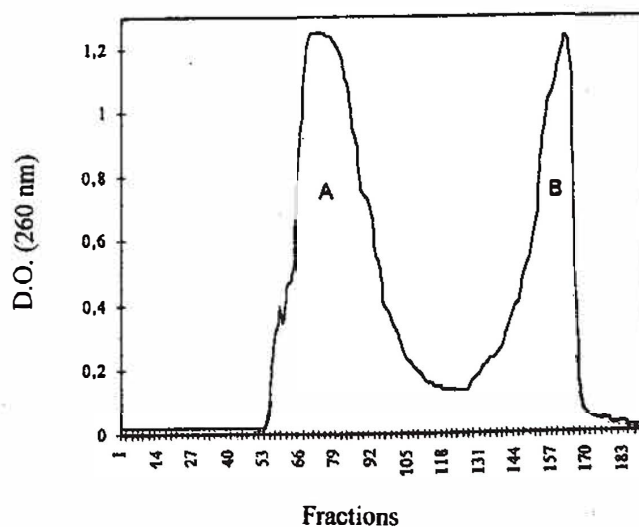


Fig. 2. Leachate molecules separation by dextrane gel chromatography.

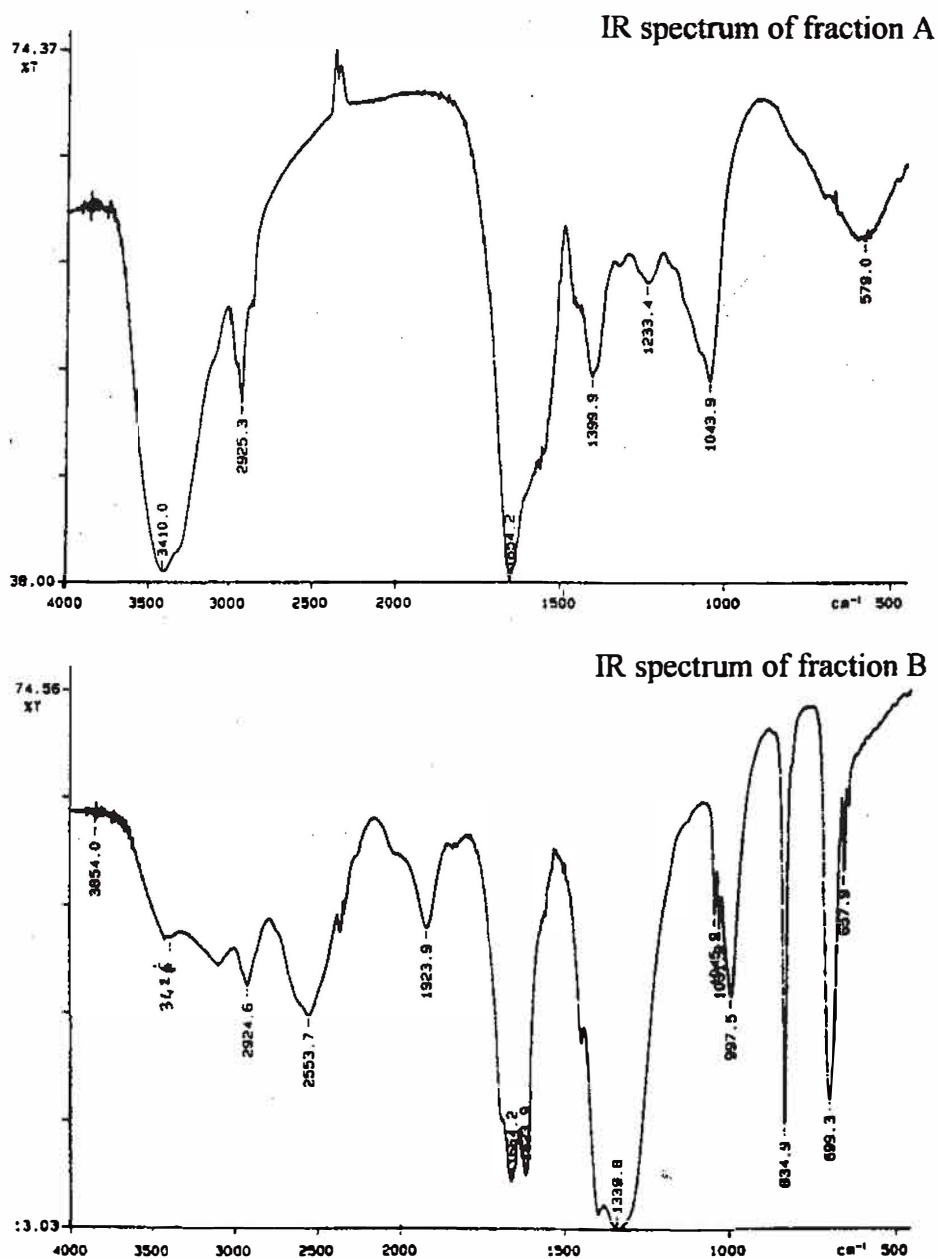


Fig. 3. Analysis of Fraction A and B by infra red spectroscopy.

ble 4). This technique allowed the detection of a significant amount of phenolic acids and alcoholic phenols: pyrogallol is moreover known to be a degradation product of lignin (Oman and Hynning, 1993).

Treatment of the Leachate

These leachates have to be removed and the Montech unit has chosen a biological solution. An initial treatment was tested on small volumes of leachate in the laboratory and led to an average reduction in the COD of 22.3% after incubation for 10 d at 37°C (Labbé, 1996). A pilot methanization plant was then installed on the site. Changes in organic matter content were monitored by comparing the contents of the effluent going into and coming out of the methanizer, which operated con-

tinuously (mean supply of 2 to 3 m³ of leachate d⁻¹). When the stabilized COD values were compared, i.e., 10 000 mg L⁻¹ at the inlet and 7000 mg L⁻¹ at the outlet, the approximate mean quantity removed was in the order of 30%. This value was less than that obtained with similar treatments (60% for Deunevy, 1987). It could be explained by the high content of salts, especially those of ammonium, which would have an inhibitory effect on the methanogenic bacteria (Ozanne, 1990).

On-site improvements were then made to this process by subjecting the effluent from the methanizer to further treatment involving lagooning with an aerator. This treatment reduced the organic content by 40%, the COD stabilizing at a value of about 4200 mg L⁻¹. The successive application of these two operations to the

Table 4. Leachate phenols composition.

	Molecular weight	phenol-Total organic C %
Acid phenol		
Cinnamic	148.15	0.418
p-coumaric	160	0.174
Sinapic	208	1.474
Aldehydic phenol		
p-OH-benzaldehyde	123	0.115
Syringaldehyde	182.17	0.265
Vanillin	152.14	0.086
Ketonic phenol		
Acetosyringone	196.17	0.805
Alcoholic phenol		
Phloretol	274	0.564
Pyrogallol	126.11	1.816

leachate was nevertheless insufficient to attain the required standards for evacuation (90 mg L⁻¹ of COD). As for the mineral load, only the ammonium had almost disappeared (4.3 mg L⁻¹) due to its utilization and transformation by anaerobic then aerobic bacteria. In contrast the concentrations of the other mineral elements (K, Na, Cl) did not change during these treatments.

Thus although these treatments were effective, the resulting effluent could still not be evacuated into the surface ground water. Another strategy was therefore selected. In view of their composition, the leachates from this landfill unit could possibly be used as crop fertilizers although the absence of toxic products would first have to be ensured. Mineral analyses had already shown that the heavy metal contents, except for Cr, were nearly nondetectable (Table 3). Several germination tests, carried out on different species, had shown that 1/1000 to 1/50 dilutions of leachate had no effect on seed germination (Labbé, 1996).

Effect of Leachate on Growth

The use of leachate as fertilizer was investigated using Italian ryegrass as test plant in pots containing soil poor in organic matter. The objective was to determine the concentration of effluent that had a positive effect on plant growth and the concentration at which it became toxic. This was based on the fact that the method of culture used in the experiment makes the root absorption of the total volume of leachate supplied by each treatment possible.

An initial experiment (Test 1) was performed using a range of leachate dilutions corresponding to a C load of between 2.6 and 1000 mg L⁻¹ (Table 2). The effect on growth was assessed from the dry weights (first and second harvests of the aerial parts plus the roots) 6 wk after treatment application (Fig. 4a). The leachate improved biomass production: 5 g of dry matter were harvested per pot at the lowest dilution (1/2), whereas only 1 g of dry matter was harvested from the control pots that had merely received distilled water. The plot of plant response to the quantity of applied leachate showed that these test dilutions were too low to attain the optimal dose and even less so to produce toxicity.

A second experiment (Test 2) was carried out to measure the effects of a wider range of leachate dilutions

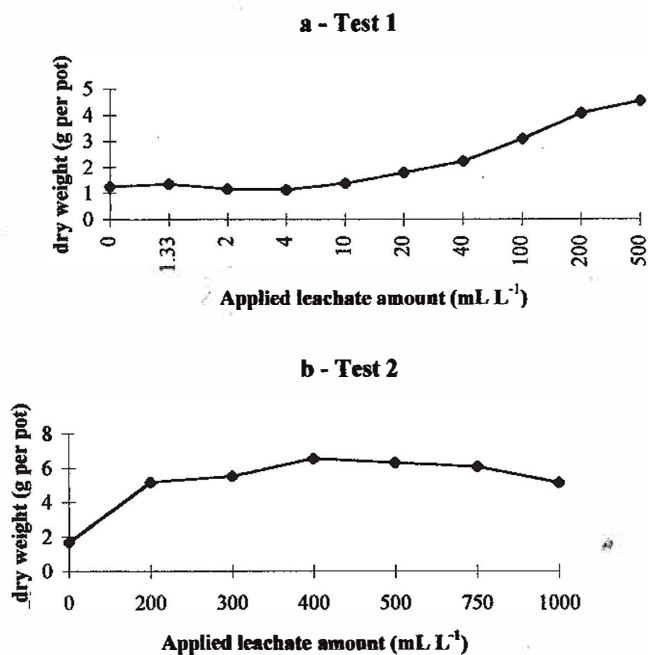


Fig. 4. Effect of the leachate on ryegrass water and mineral nutrition for (A) Test 1 and (B) Test 2.

(Table 2). The optimal positive effect, according to the amount of biomass harvested (Fig. 4b), was obtained with a concentration of 400 mL of leachate per liter of watering solution. The leachate had a depressive effect on ryegrass growth at concentrations above this.

It is essential in interpreting these effects of leachate on growth, to examine its effect on ryegrass water and mineral nutrition. Only the results obtained in Test 2 are presented so as to cover the widest range of effluent dilutions.

Water consumption was calculated by adding together the volumes of water applied daily and measured for each pot, and the known volumes of the dilutions of leachate added every 2 d (Fig. 5). These volumes were totally absorbed by the ryegrass plant roots. The

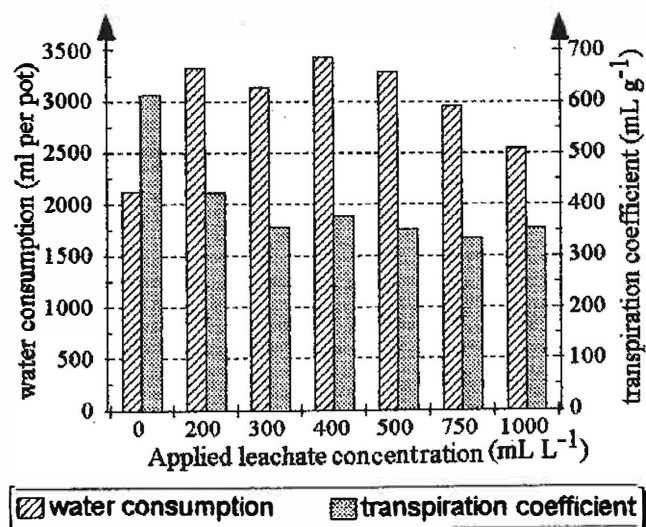


Fig. 5. Cumulated water consumption during crop growth and coefficient of transpiration.

Table 5. Total N contents (% dry matter) of aerial parts (Test 2).

Dilution applied leachate	Total N (% d.m.)	
	Harvest 1	Harvest 2
mL L ⁻¹		
0	1.23	1.04
200	3.15	3.59
300	3.39	4.22
400	3.90	4.70
500	4.44	4.59
750	4.64	5.51
1000	4.87	5.51

pots that received the highest amounts of water corresponded to the concentrations of leachate that had the most favorable effects on growth: this result is in accordance with the relationship existing between the biomass of the aerial parts, the leaf surface area and transpiration. Water consumption is insufficient, however, to fully appreciate the effect of leachate on ryegrass growth. It is preferable, from an agronomic point of view, to refer to the efficiency of the absorbed water that can be calculated from the coefficient of transpiration (volume of water expressed in milliliters, needed to be taken up by the plants to produce 1 g of dry matter). When the results were expressed in this way (Fig. 5) it was apparent that, by using leachate, the amount of water required by the ryegrass to produce a given amount of dry matter could be reduced by one-third. The coefficient of transpiration was slightly <400 at the optimal leachate dilution compared with approximately 600 with deionized water. Analogous results had been obtained in test 1 (Labbé, 1996).

As the leachate contained a high concentration of ammoniacal N, examination of the effect of this on ryegrass nutrition was indispensable. The total N contents of the two harvests of aerial parts from the pots of ryegrass (Table 5) showed that the highly favorable effect of the leachate on growth was directly associated with the mineral N content. The total N content of the aerial parts rose from approximately 1% in the plants that received deionized water from 3 to 5% when leachate was supplied.

In addition the total N content increased with the amount of ammoniacal N provided by the leachate. As with the water supply, it was necessary to determine the efficiency of this N source. Comparisons of soil analyses obtained before and after growing the plants were insufficient as they did not permit differentiation between the uptake of ammoniacal N from the leachate and that derived from nitrification and ammonification processes (Wong and Leung, 1989). In contrast analyses of the plants and their uptake provided a better indication of leachate efficiency. When the amount of N absorbed by the ryegrass was determined from the N balance

(Table 6) it was apparent that the leachate increased N uptake, the amount exported by the two harvests being around 55% with the dilutions of 200, 300, and 400 mL L⁻¹, compared with only 18% with water alone. This result was further refined by expressing the ryegrass yield (Harvest 1 combined with Harvest 2) in relation to the total N content of the aerial portions: Fig. 6 confirms that the 400 mL L⁻¹ dilution of leachate gives the best N efficiency and at the same time ensures the highest biomass production.

The other macroelements (P, K, Ca, Mg), together with a nonessential element (Na), were also analyzed in the different fractions of the harvested plants. The principal information provided by these results (Labbé, 1996) was as follows: the K contents were much higher (approximately 50%) in the aerial parts of ryegrass that received leachate. This increase was linked to the high concentration of this element in the effluent and its abundant uptake by the plants; the P levels were reduced in the second harvest and in the roots of plants watered with the leachate, indicating the existence of a limiting factor with regard to this element: the contents of both soil and leachate were very low; the Na content of the aerial parts increased steadily in proportion to the concentration in the leachate: this element is most certainly involved in the toxicity phenomena observed with high doses of leachate.

CONCLUSION

The landfill site at Montech in south-west France deals annually with 200 000 tons of refuse, consisting essentially of household waste, which is compacted in watertight pits. Anaerobic fermentation of the biological materials and the rain water that accumulates in each pit during filling leads to the production of a black foul-smelling liquid known as municipal solid waste leachate. This liquid, which accumulates at the bottom of the pits, has to be pumped out because its depth at the bottom of the pit must not exceed 50 cm.

Analysis of the chemical composition of these leachates reveals a concentration of organic molecules of very varied dimensions (the small molecules being more acidic) together with a high concentration of mineral salts (chlorides, K, Na, and ammonium). These effluents have to be treated to avoid degradation of the landfill site environment. A biological treatment was set up on the site consisting of methanization followed by aerated lagooning that reduced the concentration of organic molecules by nearly 60% and almost totally eliminated the ammonium. This was not however sufficient to allow direct evacuation of this effluent into the superficial ground water.

Table 6. Amount of N supply and amount of N exported by the ryegrass (mg pot⁻¹).

Dilution applied leachate (mL L ⁻¹)	0	200	300	400	500	750	1000
Soil N	168	168	168	168	168	168	168
Leachate N	0	222	333	443	554	832	1109
Soil and leachate N	168	390	501	611	722	1000	1277
N exported by plant	31	214	267	337	335	342	292
N exported (%)	18.4	54.9	53.3	55.2	46.4	34.2	22.9

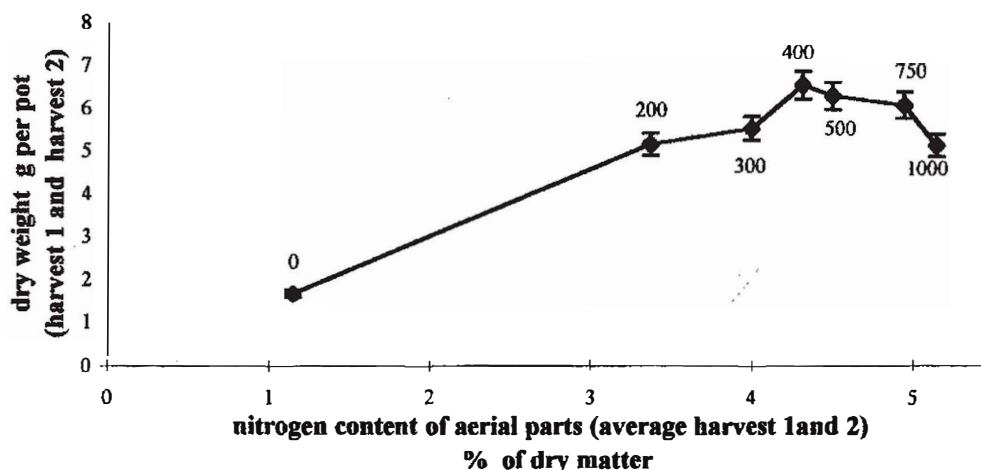


Fig. 6. Ryegrass yield in relation to the N content of aerial parts.

Another strategy was therefore selected: the possible use of this leachate could be envisaged for the fertilization of soil-grown crops or the furrow irrigation of tree plantations. Chemical analysis of the leachate demonstrated the absence of detectable concentrations of heavy metals (except for 0.4 mg kg^{-1} of chromium). This could be explained by compaction of the waste during anaerobiosis, the presence of H_2S in the biogas and the high pH of the effluents that led to precipitation of the heavy metals as sulphides. In addition biological tests showed that the leachate did not have any inhibitory effect on germination; however, these preliminary results do not allow us to draw any conclusion concerning the effects in soil after long term irrigation.

The experiment conducted on soil-grown ryegrass plants in pots enabled us to show that the roots can absorb the total volume of leachate solutions supplied to each pot. The solutions supplied had a beneficial effect on the ryegrass growth: under the conditions of the test, the optimum effect was obtained by watering each pot with 30 mL of a solution containing 400 mL L^{-1} of leachate every 2 d.

Regarding these results, in order to consider an agricultural or silvicultural application, it would be necessary to make sure that the leachate solutions are totally absorbed by the root systems of the plants and that in the long run they do not have any persistent effect on the soil and impact the ground water quality. It also is necessary to stress that the results are site-specific (CET Montech) and would have a limited application at other sites. Therefore an extrapolation to other sites would demand a full analysis of the effluents prior to their application.

At last, it will be necessary to characterize the products in organic and mineral fractions that are responsible for the beneficial effect on plant growth. This study is the subject of our next paper.

ACKNOWLEDGMENTS

The DRIMM S.A. Company must be thanked for their permission to carry out this research and, together with the Midi-Pyrénées Région, for their financial contribution.

REFERENCES

- Barber, C., and P.J. Maris. 1984. Recirculation of leachate as a landfill management option: Benefits and operational problems. *Q.J. Eng. Geol.* 17:19-29.
- Chian, E.S.K. 1977. Stability of organic matter in landfill leachate. *Water Res.* 11:225-232.
- Chian, E.S.K., and F.B. Dewalle. 1976. Sanitary landfill leachates and their treatment. *J. Environ. Eng. Division Proc.-Am.-Soc. Civ. Eng.* 102:411-431.
- Delvin, J.F. 1990. Field evidence for the effect of acetate on leachate alkalinity. *Groundwater* 26(6):863-867.
- Deunevy, J.P. 1987. Les lixiviats de décharge, approche méthodologique de leur toxicité aigüe en fonction des modes de traitement. Institut National des Sciences Appliquées Ed., Lyon, France.
- Edeline, F. 1993. L'épuration des lixiviats de décharge. *Tribune de l'eau Fr.* 566:57-65.
- Farquhar, G.J. 1989. Leachate: Production and characterization. *Can. J. Civil Eng.* 16:317-325.
- Harmsen, J. 1983. Identification of organic compounds in leachate from a waste tip. *Water Res.* 17:699-705.
- Labbé, H. 1996. Traitement biologique et valorisation agronomique d'un lixiviat d'ordures ménagères. Institut National Polytechnique ed., Toulouse, France.
- Lema, J.M., R. Mendez, and R. Blasquez. 1988. Characteristics of landfill leachates and alternatives for their treatment: A review. *Water Air Soil Pollut.* 40:223-250.
- Oman, C., and P.A. Hynning. 1993. Identification of organic compounds in municipal landfill leachates. *Environ. Pollut.* 80:265-271.
- Ozanne, P. 1990. Les lixiviats de décharge, le point des connaissances en 1990. *TSM* 6:289-314.
- Reitzel, S., G. Faquhar, and E. Mac Bean. 1992. Temporal characterization of municipal solid waste leachate. *Can. J. Civ. Eng.* 19: 668-679.
- Vickery, P.J., J.R. Lutton, and R.D. Tourenq. 1995. A simple procedure for colorimetric determination of organic carbon in soil. *Commun. Soil Sci. Plant Anal.* 26:899-911.
- Wong, M.H., and C.K. Leung. 1989. Landfill leachate as irrigation water for tree and vegetable crops. *Waste Manage. Res.* 7:311-324.