

Methane Oxidation in Optimised Landfill Cover Layers under Different Seasonal Conditions

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Abstract: Methane emissions from waste landfills are situated at third rank of anthropogenic methane sources. These emissions are mainly caused by inadequate gas collection systems and uncontrolled emissions from old dumps. A low-cost alternative or an additional measure to the conventional methods is the use of suitable landfill cover layers, e.g. made of compost, which provide appropriate conditions for microbial methane oxidation. We received promising results from laboratory tests, which are now reviewed in a large-scale outdoor experiment. The previous results from these experiments show that mature compost support appropriate conditions for microbial methane oxidation. Even under winter conditions all methane could be oxidised in the cover layer. The data from the differently designed test cells show that it is very important to install a gas distribution layer below the compost cover and to dimension the thickness of the cover layer appropriately, in order to reach homogenous and efficient methane oxidation.

Key Words: Old landfills, landfill gas, greenhouse effect, methane-oxidation, landfill cover, waste compost

1 Introduction

Uncontrolled emitted landfill gas contributes to the greenhouse effect due to its high content of methane. Worldwide about 40 million tons of methane result from waste landfills. These emissions are situated at third rank of anthropogenic methane sources and are mainly caused by inadequate gas collection systems and uncontrolled emissions from old dumps and unauthorised open dumping. With traditional gas collection systems only 40 to 60 % of the produced gas can be collected and reused or safely disposed of. Considering estimations from the IPCC, methane emissions from landfills will increase significantly. In the year 2025 these emissions may be 60% larger than in 1995 especially on the basis of the increase in population in developing countries (Meadows et al., 1997). In those countries municipal solid waste and therefore landfills will increase but landfill technology, for example landfill gas collection systems, will be too expensive or technically impractical to implement. A low-cost solution for those countries as well as an alternative or an additional measure to the conventional degasification methods is the use of suitable landfill cover layers, e.g. made of compost, which provide appropriate conditions for microbial methane oxidation.

The process of methane oxidation consists of the conversion of methane into water, carbon dioxide and biomass by means of microbial activity. Methane oxidation takes place in many natural systems and soils without human interference and is an important sink for natural methane emissions. Methane oxidation is based on a number of determining factors, such as the existence of methanotrophic microorganisms, their supply with sufficient oxygen and methane, a suitable substrate that offers adequate nutrient supply, porosity and moisture content. These factors have a strong impact on the oxidation-capacity. High oxidation rates could be received in municipal solid waste compost and sewage sludge compost tested in continuously charged soil columns in the laboratory (Humer et al. 1999). The results show that mature compost is a suitable substrate for methane oxidation and that it is possible to

foster the natural potential of methanotrophic bacteria by creating suitable ambient conditions. An average methane quantity usually released from an about 15 m high municipal solid waste landfill ($240 - 300 \text{ l CH}_4/\text{m}^2\text{d}$) and a landfill for bio-mechanically pretreated residual waste ($35 - 45 \text{ l CH}_4/\text{m}^2\text{d}$) could be entirely decomposed in mature waste compost.

Further test series were carried out in a climatic chamber to test the methane oxidation potential at various temperatures. Also a large scale field experiment was started in summer 1999 on an municipal solid waste landfill in Lower Austria to examine the methane oxidation capacity under real and different seasonal conditions.

2 Laboratory experiments at various temperatures

2.1 Materials and methods

These experiments were carried out at various temperatures (4, 10, 12, 18 and 30 °C) in a climatic chamber with gas-proof, transparent columns of acrylic glass (Figure 1). The compost was filled in to a depth of 60 cm and methane was continuously added at the bottom. Air was blown in through an open passage above the substrate. Throughout the experiment, the temperature and gas composition at different levels (10, 30 and 50 cm deep) inside the columns as well as exhaust air were measured. Methane, carbon dioxide and oxygen concentrations inside the columns as well as in the exhaust air were assessed. The test was carried out in quadruplicate. The methane load was about $150 - 160 \text{ l CH}_4/\text{m}^2 \text{ d}$. The experiment lasted for about 160 days.

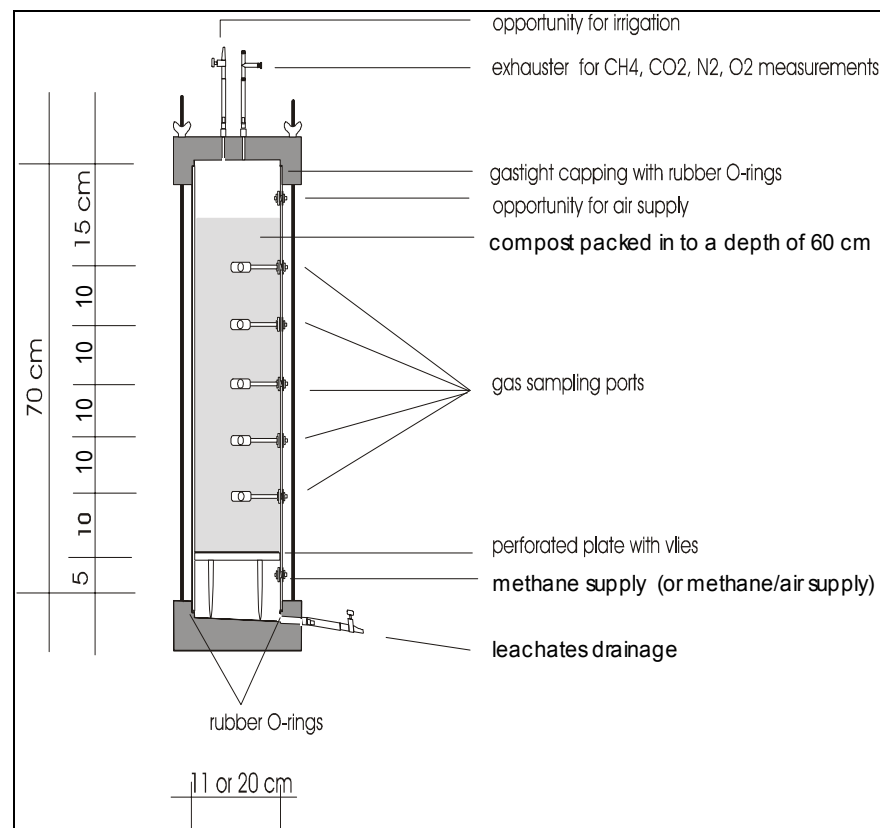


Figure 1. Schematic diagram of a soil-column used in the laboratory tests

Mature sewage sludge compost (about 2.5 years old) was used for this test. The data of the selected compost is shown in table 1.

	Sewage sludge compost
Conductivity [mS/cm]	1.21
pH value	7.0
NH ₄ ⁺ -N [ppm dry matter]	1
NO ₂ -N [ppm dry matter]	n.d.
NO ₃ -N [ppm dry matter]	1040
TKN [% dry matter]	1.1
Organic content [% dry matter]	26
TOC [% dry matter]	14
Phosphorus [% P ₂ O ₅ dry matter]	2.8
Respiration activity in 7 days [mg O ₂ /g dry matter]	1,9

Table 1: Data of the sewage sludge compost used in the experiment (n.d. = not detectable)

2.2 Results

The test started at a temperature of 18 °C and after an adaptation time of about 6 days all of the supplied methane could be oxidised. By reducing the temperature to approx. 4 °C the oxidation rates decreased to about 70 – 80 % and increased immediately when the temperature was raised again. The curve of the oxidation rates over the whole experiment at different temperatures is shown in figure 2.

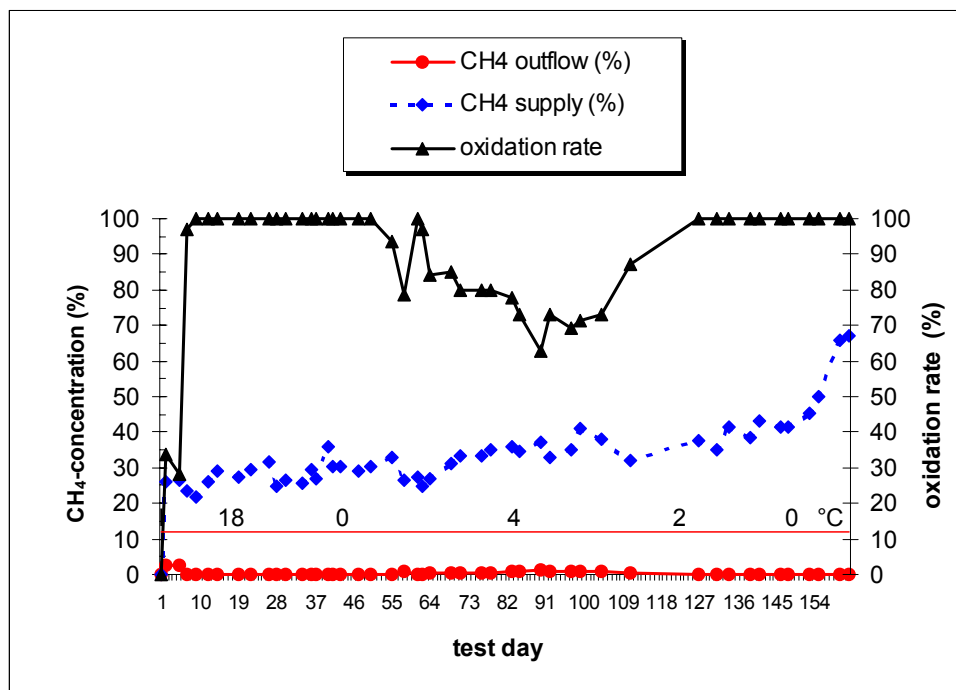


Figure 2: Curve of the methane oxidation rates during the laboratory experiment at different temperatures

Figure 3 shows the mean quantities of methane which were oxidised during the experiment at different temperatures. “Mean CH₄- load“ indicates methane load supplied in each of the experiments. The “oxidation rate after adaptation” at 18 °C (starting temperature) indicates the methane turnover after the first few days (after the adaptation phase).

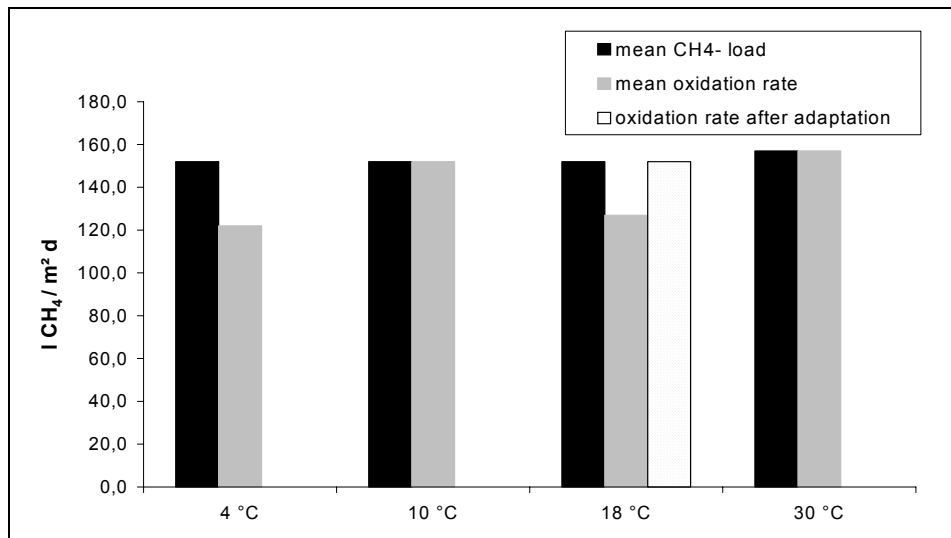


Figure 3: Mean quantities of methane oxidised at different temperatures

As shown in figure 3 approx. 150 l methane /m² d (all of the supplied methane) were oxidised at temperatures of 10, 18 and 30 °C and about 120 l methane /m² d at 4 °C.

3 Field experiments

3.1 Test cells

The results of the laboratory tests are now being reviewed in a large-scale field experiment which was started in June 1999 on a landfill for municipal solid waste in Lower Austria. The investigations will extend until autumn 2001. Several test cells (each approximately 25 x 25 m) with compost materials of different thickness and composition were installed. The surrounding area of the test cells was made widely airtight by installing geosynthetic clay liners. The various landfill covers on the test cells are designed as shown in table 2.

test cell 1: - 0.9 m sewage sludge compost - 0.3 m coarse gravel (gas distribution layer) - about 10 – 15 m municipal solid waste	test cell 2: - 0.9 m MSW- compost - 0.3 m coarse gravel (gas distribution layer) - about 10 – 15 m municipal solid waste
test cell 3: - 0.4 m sewage sludge compost - about 10 – 15 m MSW	test cell 4: - 0.3 m sewage sludge compost - 0.3 m compacted loam - about 10 – 15 m MSW
test cell 5: open landfill body (10 – 15 m municipal solid waste) as a control cell	

Table 2: Design of the test cells

Table 3 shows some data of the used composts analyzed at the beginning of the experiment.

	Sewage sludge compost	Municipal solid waste compost
Conductivity [mS/cm]	1.0	2.3
pH value	7.2	7.8
Water capacity [% dry matter]	120	90
NH ₄ ⁺ -N [ppm dry matter]	5	100
NO ₂ -N [ppm dry matter]	n.d.	n.d.
NO ₃ -N [ppm dry matter]	230	230
TKN [% dry matter]	1.11	0.97
Organic content [% dry matter]	27	27
Respiration activity in 7 days [mg O ₂ /g dry matter]	1.4	2.2

Table 3: Data of the waste composts used as landfill cover materials in the field experiment; n.d. = not detectable

The landfill gas production is still high. A gas extraction system operates on the landfill but the remaining gas emissions are on the average between 0.1 to 0.3 m³. m⁻²d⁻¹. The gas composition and temperature within the cover layers as well as in the landfill body at different depths are measured by a close net of fix installed gas-probes and temperature-probes. The methane emissions at the surface of the cover layers are also measured in periodic intervals in a close screen of about 1.5 x 1.5 meters using a portable Flame-Ionization-Detector.

3.2 Results

The previous results from the field experiment are very promising. No methane emissions were measured throughout the whole year at the surface of test cell 1 and test cell 2, which are regarded as the “optimal variants” with a gas distribution layer and a sufficient thickness of the compost layer. Whereas on test cell 3 (only 0.4 m compost layer direct on the landfill) and test cell 4 (combination of 0.3 m compost layer and 0.3 compacted loam direct on the landfill) and certainly on test cell 5 (control cell without any cover) inhomogeneous but sporadic reasonably high methane emissions were detected. In this case methane probably escapes at cracks because of a missing gas distribution layer. These emission slightly decreased during winter. The reason may be on the one hand a general decline of the landfill gas production at winter temperatures, on the other hand part of methane emissions may be captured under the frozen snow cover.

Measurements at the fix installed gas probes show the gas concentration within the cover layers as well as the location of the methane oxidation horizon. In test cell 1 and 2 methane oxidation takes place between a depth of 0.4 to 0.9 m depending on the density and porosity of the two different compost substrates. In the coarse sewage sludge compost mixed with wood chips oxygen penetrates deeper into the cover layer than in the fine sieved municipal solid waste compost ($\varnothing \leq 20\text{mm}$). Therefore the methane oxidation horizon is situated deeper in test cell 1 than in test cell 2 (see figure 4). During winter in both test cells the methane oxidation layer shifted downwards. Figure 4 shows the concentration and temperature profiles of test cell 1. Most of the methane is already oxidized at the interface of the gas distribution layer and the compost cover. Also during winter no methane was detected in the upper 0.8 m of the cover layer and the temperatures were still reasonably high within the cover layer due to the exothermic process of the microbial activity of methanotrophic bacteria.

Stoichiometric examinations show a significant change in the $\text{CO}_2:\text{CH}_4$ - ratio within the cover layers of test cell 1 and 2, which is typical for methane oxidation. It indicates a clear increase in CO_2 and a total decomposition of methane. Above the methane oxidation horizon the CO_2 - concentrations show a relatively constant decrease due to the rarefaction effect with air.

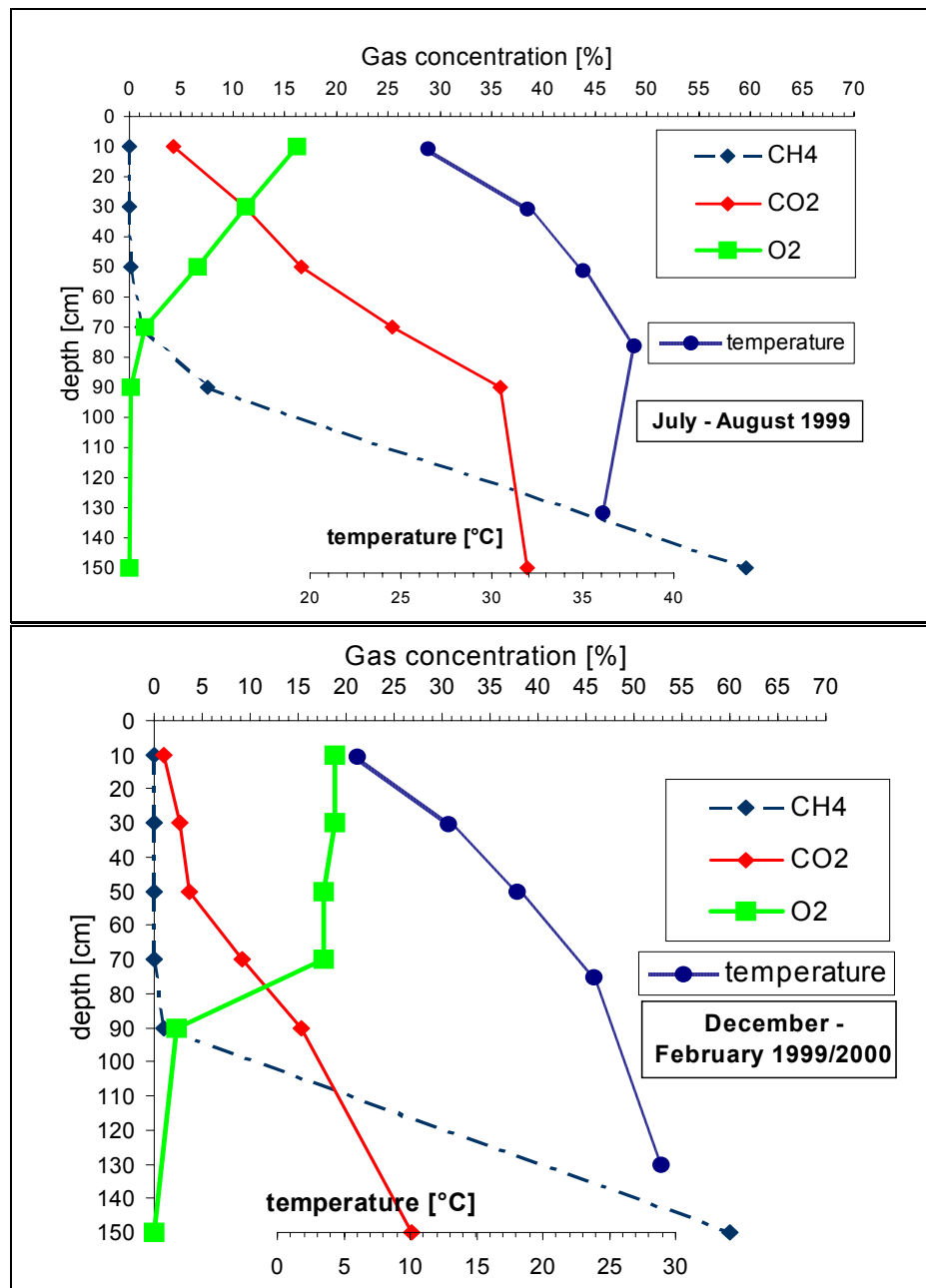


Figure 4: Gas concentration and temperature in test cell 1 (0.9 m sewage sludge compost and 0.3 m coarse gravel) during summer and winter

In test cell 3 and test cell 4 high methane concentrations were measured in the upper 0.1m of the cover layer during winter and no significant change in the $\text{CO}_2:\text{CH}_4$ - ratio occurred. This is due to the thickness of only 0.3 m respectively 0.4 m compost layer in both test cells and thus the temperatures were too low in the cover layers for an effective microbial activity during winter.

4 Technical design of a methane oxidation layer

Following technical and constructive requirements on the methane oxidation layer as well as demands on the quality of the substrate could be derived from the previous results:

- The substrate must be a mature compost (respiratory activity in 7 days at least $< 8 \text{ mg O}_2 \cdot \text{g}^{-1} \text{ DM}$) with stable organic matter and low ammonium concentrations ($< 350 \text{ ppm}$) as well as no nitrite.
- The compost must have structure stability and an adequate porosity (e.g. high content of wooden chips with grain size distribution 20/63 mm) even with a high water content in the long term, to guarantee a satisfactory permeability of oxygen and methane.
- The compost must provide microorganisms with an adequate and easily available nutrient supply (especially nitrogen, phosphor) to support microbial activity.

The design of a methane oxidation layer should look like as shown in figure 5.

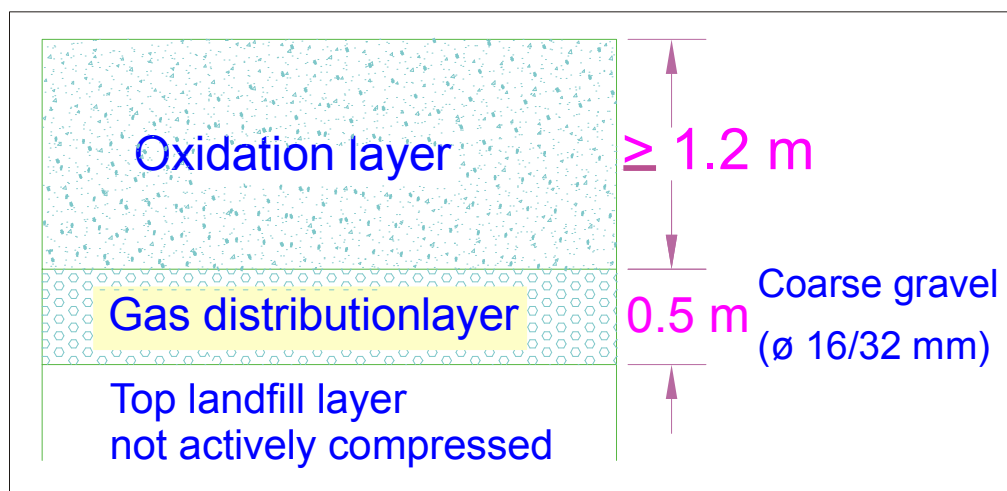


Figure 5: Design of a methane oxidation layer

Very important is the installation of a gas distribution layer (e.g. made of coarse gravel deficient in lime) below the compost layer to create a homogenous load of landfill gas. Between the gas distribution layer and the compost cover no geotextile should be placed, because at such interfaces chemical and physical conditions change rapidly and high microbial activity occurs, which often causes clogging of the geotextil. In order to hold up the functionality of the gas distribution layer for a long time it is necessary to use a material deficient in lime and a sufficient thickness of this layer. When dimensioning the compost layer various factors must be considered, for example, the oxygen penetration depth, settling behavior, desired vegetation, dependence of temperature inside the landfill cover on ambient temperature. The minimum thickness of the compost should be 1.2 m at the beginning. The compost should be placed without any technical or artificial compaction to guarantee a sufficient porosity and satisfactory permeability of oxygen and methane. The expected natural settlement of the compost layer within the first two years will be approximately 20 - 30 % due to mineralization, rainfall and natural compaction.

5 Conclusions

The results conducted from our previous experiments reveal that the method of microbial methane oxidation in suitable cover layers can be applied for gas emission control on old landfill sites, on landfills of mechanically biologically pretreated waste as well as for landfill aftercare or as an additional measure to technical gas extraction systems. In order to achieve high oxidation rates the oxidation layer must ensure optimal ambient conditions for methanotrophic bacteria. The active support of microbial methane oxidation by optimizing landfill covers may also be an inexpensive way to curb ecologically harmful methane emissions from landfills and open dumps, especially in developing countries where technical landfill gas collection systems are too expensive or technically impractical to implement.

A further benefit of compost is its high water holding capacity. In combination with a type of vegetation which have a high transpiration capacity it is also possible to minimise leachate generation. This alternative cover layer is an open system, which allows the entry of a certain precipitation to the landfill, by which the microbial decomposition processes can be kept alive and can be ended faster. The cover layer itself has such a high water storage capacity, to be able to store the precipitation water and feed it to the plants. The water is eliminated over plant transpiration and evacuated into the atmosphere.

Mature waste composts provide suitable conditions both for methane oxidation and for leachate reduction and the use of such composts as a substrate for cover layers may be an ecological and economical suitable suggestion. This simple and low-cost method help us to reduce greenhouse effective gas emissions from landfills and to provide a small contribution to the protection of our global climate.

6 References

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