Can Phytocapping Technique Reduce Methane Emission From Municipal Landfills?

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ABSTRACT

Landfill gases, predominantly methane and carbon dioxide, are produced by the biodegradation of organic wastes. Biodegradation occurs, if the water comes in contact with the buried waste. Techniques such as clay capping are used to minimise percolation of water into the landfill, or gas collection system installed to reduce methane emission into the atmosphere. The use of clay cap has proven not effective in avoiding percolation of water and the gas extraction technique is found expensive for many landfills in Australia. Thus a new technique “Phytocapping” is being trialled at Rockhampton’s Lakes Creek Landfill. Results from this study show that Phytocaps can reduce surface methane emission 4 to 5 times more than the adjacent un-vegetated site, and the thick cap (1400 mm) reduces surface methane emission 45% more than the thin cap (700 mm). The root zone effects of 19 tree species on methane emission were also examined.

KEYWORDS: Phytocapping, landfill, methane, native species, soil, portable methane gas meter, greenhouse gas, global warming, Phyto cover, ET capping,

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Venkatraman is also working with the Central Queensland Local Government Association as Coordinator – Technical Services (CQ Waste Management) and is responsible for promoting best management practices for solid waste management amongst regional councils in Central Queensland. Kartik takes part in community service activities, including organising environmental conferences. He has been part of the organising committee of the Environmental Research Event (ERE) 2006 and 2007.

Associate Professor Nanjappa Ashwath has worked extensively on the use of Australian native species in land remediation (drought, salinity, acidity and waterlogging affected sites). His recent focus has been on phytoremediation of heavy metal (Ni, Mn, As, Cd) contaminated sites and conservation of rare and threatened flora. He is one of the chief investigators of the Australian Alternative Capping Assessment Program (A-ACAP) and the principal investigator of a Rail CRC project. He specialises in matching plants to degraded sites, and enjoys working on challenging topics such as ecosystem reconstruction on disturbed mine sites or industrial areas.

INTRODUCTION

In Australia, around 95% of the waste ends up in landfills (CSIRO, 2001 & McLaughlin *et al.* 1999). Hence, their construction and remediation will continue to occur, as land filling is the most economical and easiest method of waste disposal (CSIRO, 2001). Landfills mostly contain putrescible wastes that often decompose and produce landfill leachate and landfill gasses (mostly methane and carbon dioxide), when they come in contact with water (Jones and Nedwell, 1993).

Soil is the major source of methane (Mosier, 1998) and it also acts as the biological sink (Hutsch, 2001). Besides wetlands and rice paddies, landfills are the important contributors to the atmospheric methane increase (Giani *et al.* 2002). Bingemer and Crutzen (1987), Richards (1989) and Bogner (2003) estimated 9-70 Tg/yr methane would be emitted from the landfills alone. The rate of emission of methane was found to range from 0 - 100 mmol/m²/h (Jones and Nedwell, 1993; Nozhevnikova *et al.* 1993). De Visscher (1999) found highly variable rates of methane emission (0.013 – 10,400 mmol/m²/h), whereas Tohijima and Wakita (1993) reported up to 650 mmol/m²/h. The highest rates (28000 mmol/m²/h) of methane emission were recorded by Bogner and Spokes (1997).

Methane oxidation rates have been reported to be very high at a moisture content of 15% and temperature of 25-30 °C in controlled laboratory conditions (Boeckx and van Cleemput, 1996) and in zones at different depths 20 cm and 30 cm by Kightley *et al.* (1995). Rates for methane oxidation in landfill soil covers were reported to be as high as 150 g m⁻² d⁻¹ (Knightly *et al.* 1995).

Landfill gas comprises of methane (45-60% v/v) and carbon dioxide (40-60 % v/v) (Swarbick and Dever, 1999). Studies conducted by Duffy *et al.* (1996) and Yuen (1999) in various landfills across New South Wales (NSW) and Victoria reported methane concentrations ranging between 50% and 62% in NSW, and up to 61% in Victoria. Carbon dioxide concentrations were 35% to 42% in NSW and 38% in Victoria. Methane is an important component of greenhouse gasses, and its total positive climate-forcing attribute over the last 150 years has been estimated to be 40% of that of carbon dioxide (Hansen *et al.* 1998). Thus, minimising anthropogenic methane emission will make a substantial contribution to reducing global warming. The easiest measure to prevent methane emission from landfills is through the installation of active gas recovery systems (Borjesson *et al.* 2000). This technique is expensive and is not economically viable for small landfills. Methane from landfills have been extracted, recovered and used for various purposes such as bio-energy generation (DeWalle *et al.* 1978). This process has considerably reduced the proportion of methane being contributed by the landfills. Establishment of Phytocaps would offer an additional and economical way of reducing methane emission from landfills.

At present, placement of compacted clay (conventional cover) over the waste has been the most commonly used method of remediating landfills (Fig 1) (EPA 2005). The purpose of this is to minimise percolation of water into to the waste, so as to minimise methane emission and landfill leachate generation. Recent studies that rely upon long-term monitoring of field trials carried out in different agro-climatic regions of USA concluded that the clay caps fail to limit percolation of water into the refuse due to cracking and drying of the clay cap (Albright *et al.* 2004). Furthermore, the clay covers do not allow for optimal interaction of methane with oxygen, which is a must for methane oxidation (Abichou *et al.* 2004).

Figure 1: Environmental Protection Agency (EPA) recommended clay capping design in Queensland, Australia (<http://www.epa.qld.gov.au/publications?id=1312>)

Alternative methods of remediating landfills, both to minimise percolation of water and to oxidise methane are therefore required. These alternatives include natural attenuation of landfill-generated methane through aerobic oxidation in landfill soils (Grossman *et al.* 2002), and the use of ‘Phytocapping’ systems (Fig 2) (Ashwath and Pangahas 2005; Venkatraman & Ashwath 2005). In Phytocapping technique, selected plant species are established on an unconsolidated soil placed over the waste, so that soil will act as the ‘storage/sponge’ and the plants as ‘bio-pumps’. For an effective site water balance, it is important that appropriate plant species are chosen and the soil depth optimised.

Figure 2: Conceptual model of a Phytocap (Figure changed)

In contrast to conventional clay capping (where the water is prevented from entering the clay cap), the Phytocapping technique allows the water to enter into unconsolidated soil, so that this stored water will become available for plant growth and transpiration (bio-pumping). The Phytocapping technique is also known as ET capping (Benson, 2002), as the water loss from the system depends on transpiration and soil evaporation. The Phytocapping technique is known to have several advantages over clay capping. These include, halving the cost of landfill remediation, acting as biodiversity corridors, providing aesthetic values to the adjacent urban community, and in some cases, introducing economical benefits such as timber and fodder.

The bio-pumping capacity of the Phytocapping system is dictated by two of its major components; viz the thickness (and the soil type) of the unconsolidated soil layer, and the type of trees/vegetation established on the cap. Amongst these, the soil component contributes to as high as 75% of the Phytocapping cost. Thus, efforts are being made to optimise/reduce the thickness of the soil layer being used in Phytocapping, without compromising its ability to limit percolation of water into the refuse. Varying soil thickness (without plants) could have

an impact on methane emission (Giani *et al.* 2002, Nozhevnikova *et al.* 1993). This paper tests whether the soil thickness would have any impact in a Phytocapped system. The study also compares the performance of the Phytocap with its adjacent un-vegetated site, and records the variability in methane emission amongst the 19 tested plant species.

METHODS

Details of establishing the Phytocapping trial are provided in Venkatraman and Ashwath (2005), Venkatraman and Ashwath (2006), Venkatraman *et al.* (2006) and Venkatraman and Ashwath (2007). In summary, a large-scale replicated (twice) field trial (5000 m²) was established at the Lakes Creek landfill in Rockhampton (Fig 3). Two soil treatments viz. a thick cap (1400 mm) and a thin cap (700 mm) (Fig 3, top) were placed over a 22 year-old landfill that contained municipal waste up to a depth of 7 m. On each cap, 21 tree species were established each in 6 m x 6 m plots, with 18 plants/plot/species (Fig 3, bottom) which were thinned to 9 plants/plot/species after two years of planting. The experimental site was mulched with shredded green waste (10 cm deep), and the plants were drip irrigated. Various plant and soil parameters were monitored over three years and the results of methane emissions only are reported here.

Figure 3. Establishment of the Phytocapping trial at Lakes Creek landfill, Rockhampton. Top: Placement of thin and thick soil caps over the waste. Bottom: 21 tree species were established on each of these soil treatments.

Methane emission was measured within each of the 19 plots (measurements from two plots omitted, as the plants died in these plots) in both thick and thin capping treatments, using a portable methane gas meter (Gastech, Australia, 2004). Methane concentrations were also monitored in the adjacent areas of the experimental site that were kept devoid of vegetation (bare site that contained 500 mm to 1000 mm interim uncompacted soil cover over the refuse).

Prior to determining methane concentrations in the landfill, diurnal variations in methane emission were determined by monitoring methane continuously over 24 hours at 17 months (19 February 2005), 18 months (15 March 2005) and 19 months (22 April 2005) of establishing the trial respectively. Methane emission was measured using a portable methane gas meter (Gastech, Australia, 2004). Poly Vinyl Chloride (PVC) tubes (200 mm diameter) that were buried around plants to a depth of 300 mm (root zone) and capped. During methane measurement, the cap was removed and the gas meter probe was inserted into the PVC tube to a depth of 20 cm below the soil surface. Methane concentrations were recorded after the meter readings were stabilised. Concentrations of carbon dioxide, oxygen and hydrogen sulphide were also recorded. Based on the above observations, all further methane readings were recorded between 9 am and 12 noon. Concentrations of CO₂, O₂, and the H₂S in the tube were also recorded.

For surface methane measurements, the inlet tube of the methane meter was connected to a 70 mm diameter plastic funnel, which was placed inverted on the surface. The funnel was twisted left and right to ensure proper positioning and sealing to minimise the meter pulling air from outside the enclosed area. For surface measurements, up to five readings were taken randomly within each plot/species, whereas for root zone measurement, one measurement was taken per plot/species using permanently installed PVC tubes. The monitoring was carried out nine times during 2005-2006 (2 to 3 years after planting), to represent winter, summer and rainy seasons.

The data were tested for outliers and homogeneity of error variances before subjecting to analysis of variance using Genstat v 8.0. Standard errors of means are provided where no ANOVA was performed.

RESULTS AND DISCUSSION

The initial readings collected around 9 am were found high and consistent in both ‘thick’ and ‘thin’ caps (Fig 4). These timings also coincided with the pleasant times for field operation in the tropical climate of Rockhampton. Thus, all further methane monitoring was carried out between 9 am and 12 noon Australian Eastern Standard Time (AEST).

Figure 4. Diurnal variations in methane concentrations in the root zones of plants established in thick (left) and thin (right) caps on the Phytocapped landfill site. Note much higher concentrations of methane in the thin cap. Values are means and standard errors of three observations collected during March 05 and May 05).

Comparison of the thick and thin caps for methane concentrations shows a consistent trend between the two types of caps in both the surface and root zone measurements. The root zone methane concentrations were consistently low in thick cap than in thin cap for all the tested species (Fig 5). The surface methane concentrations were also low in thick cap for the majority of the tested species (Fig 5).

Figure 5. Methane concentrations in the root zone (30 cm below the surface) (A), and on the surface (B). The values are means of nine observations collected over three seasons (Mar 05-Jan 06). The bar represents lsd at $P < 0.05$.

The methane concentrations were significantly ($P < 0.001$) lower on the surface than in the root zone for majority of the tested species (Fig 6). The experimental site was mulched with shredded green waste both in thick and thin caps. The significantly ($P < 0.001$) lower methane concentrations recorded on the surface than in the root zone could have been contributed by the root system, soil and the mulch (Bogner *et al.*, 1997 and Christopherson *et al.*, 2000). The fact that the mulch thickness was similar amongst all the established plant species, and the

methane concentrations were varying amongst different species, suggest that tree roots and the soil have also contributed to methane oxidation.

The ability of the tree roots to oxidise methane may be assessed by examining the difference between the surface and root zone methane concentrations. Figure 6 shows large variability between plant species in their root zone methane oxidation. Some species, such as *Lophostemon confertus* and *Dendrocalamus maroochy* showed marked differences between the surface and the root zone methane levels, indicating their improved ability to oxidise methane, as opposed to *Glochidion lobocarpum* which showed no difference between the two layers.

Although some general inferences can be made regarding species differences in methane oxidation, no firm conclusions can yet be drawn about methane oxidation under these species, due to lack of information on the concentrations of methane going through the root system, spatial variability in its emission in the root zone, and most importantly, due to lack of information on species rooting patterns in the upper most layer of the soil. Hence, glasshouse trials are being planned to examine inherent differences between plant species in methane oxidation.

Figure 6. Comparison between root zone and surface methane concentrations. The values are averages methane emission from thick and thin caps (9 observations over 3 seasons). The bars represent standard errors of means (n=2).

Overall, the thick cap was 45% more efficient in reducing methane emission compared to the thin cap. The significantly ($P < 0.001$) lower levels of methane in the thick cap than in thin cap could be due to greater exposure of methane to larger volume (depth) of the soil, or an increased rate of oxidation by the soil bacteria (Bogner *et al.* 1997; Khalil *et al.* 1998; Kallistova *et al.* 2005). The differences between thick and thin caps were much larger for the root zone methane (Fig 5) than for surface methane (with the thick cap having less methane than thin cap). These results clearly demonstrate that the thicker the soil layer, higher will be the methane oxidation. Since the placement of thicker layers of soil can be highly expensive in urban areas, a decision has to be made on the appropriate thickness of the soil to be placed over the refuse. This decision, should take into consideration the thickness needed to minimise the entry of water into the refuse, as well as the thickness needed to oxidise methane. Consideration of the thickness needed to reduce percolation of water is more important than that needed for reduction in methane emission, as the landfill operators are required by law to limit the amount of water that enters into the landfill, but they have no mandate for reducing the methane emission.

The area adjacent to the experimental site had similar depth of interim soil over the refuse as in thin cap, but it had no mulch placed over it. Thus the surface methane concentrations were significantly ($P < 0.001$) lower in the Phytocap (thick or thin) than in the adjacent un-vegetated site (Fig 7). Phytocaps can therefore reduce methane emission from 400 % (thin cap) to 500% (in thick cap) compared to a bare (un-vegetated) site.

The methane data that were collected either at the surface or in the root zone were influenced by the nature of the refuse buried underneath, and the moisture content, or access to moisture source by these refuses. Since the type of the refuse buried under Phytocap could differ markedly (e.g. car bodies, timber to pure domestic waste), large spatial variation in methane emission can be expected from the root zone. Despite such spatial variations, thick cap showed greater levels of oxidation, particularly in the root zone. Therefore it can be concluded that the thick cap will minimise methane emission much more effectively than a thin cap. Since the cost of placing unconsolidated soil is very high, it is important to optimise the depth of soil cap, considering local climatic conditions (e.g. rainfall and evaporation) as well as the cost of the soil. Based on methane emission and plant growth in thick and thin capping systems over the past three years, it seems that 100 cm to 150 cm thick layer of unconsolidated soil would reasonably be effective in reducing methane gas emission in

Rockhampton area. This inference should however be revised for each site, considering water retention characteristics of the soil as well as the climatic conditions of that location (rainfall and potential evaporation). The use of predictive models such as HYDRUS 1D and HYDRUS 2D is being considered to optimise site-specific soil depth for Phytocapping systems.

Figure 7: Surface methane concentrations in the Phytocapped site and its adjacent bare site.

CONCLUSIONS

Phytocapping technique significantly reduces (4 to 5 times) methane emission from landfills. The use of thick layer of unconsolidated soil reduces methane emission much more efficiently than a thin layer. Plant species differ in their root zone methane emission, but the species effects of plants *per se* was confounded with those of soil and mulch. Further experiments are underway to elucidate genotypic differences in methane oxidation.

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