38th WEDC International Conference, Loughborough University, UK, 2015

WATER, SANITATION AND HYGIENE SERVICES BEYOND 2015:
IMPROVING ACCESS AND SUSTAINABILITY

Faecal sludge treatment by vermifiltration: proof of concept

C. Furlong, W.T. Gibson, R. Patankar, S. Savant & A.Oak (United Kingdom)

BRIEFING PAPER 2308

The objective of this study was to determine if composting worms and their cocoons are able to survive in and digest faecal sludge. Eighteen vermifilters with different worm and cocoon densities were set-up, fed with faecal sludge (from portable pour-flush toilets) and ran for 38 days. Samples of the sludge, effluent and vermicompost were analysed for pH, total solids, chemical oxygen demand, faecal coliforms and Ascaris spp. number and viability. Worm and vermicompost mass, and cocoon numbers were assessed at the end of this period. It was found that the composting worms survived in these conditions and cocoons hatched. The validity of the sludge analysis results are questioned in this paper and without these results only estimates of effluent treatment and solids conversion could be made. Although this study was not completely definitive it has shown that worms are capable of converting faecal sludge into vermicompost and cocoons hatch in its presence. This trial was undertaken in India.

Introduction

There are currently over 12 million people living in humanitarian camps worldwide and 3.2 million of those people are living in camps in Africa. Providing sustainable sanitation for these populations is a huge challenge. Present systems such as pit latrines require frequent emptying, which is either done by tanker or manual labour and the faecal sludge is either transported off site or buried. The onsite processing of faecal sludge within camps by composting worms may provide a solution. It would be more cost effective than transporting the waste out of the camp. The composting worms could potentially process the faecal sludge, reducing its volume by over 90% (Furlong et al., 2014a,b). Additionally worms have the potential to reduce the pathogen load including parasitic worm eggs in the end product to a level where it can be applied safely to land (Eastman et al., 2001). Sewage sludge has been traditionally vermicomposted (Eastman et al, 2001) and vermifilters have been used to treat fresh faeces (Furlong et al., a,b). To our knowledge no other groups have explored the use of a vermifilter (filter which contains worms) to treat fresh (not composted or dried) faecal sludge. In these systems the solids are trapped on top of the filter, where they are processed by the worms, but the liquid passes through the filter.

This briefing paper reviews the results from experiments and assesses the potential of the technology in this context. The objectives of this study were:

- To determine the ability of composting worms to digest faecal sludge
- To explore the key factors, which may affect sludge processing such as worm density
- To determine the volume and pathogen reduction, which occurs during the conversion to vermicompost

Methodology

The vermifilters and sludge are housed at Rajiv Gandhi Infotech Park Sewage Treatment Plant in Hinjawadi, 20km outside the city of Pune in India. Eighteen cylindrical plastic vermifilters (referred to as V1 to V18) were constructed with an internal diameter of 400 mm (surface area 0.13 m^2) and a height of 800 mm. There was a tap at the bottom of the vermifilter to allow the effluent to be drained. Under the rim of the lid a row of 1 mm holes, spaced every 20 mm, were drilled to allow for airflow. The vermifilter was filled using 100

mm layers of the following material from bottom to top: 150-300 mm gravel, 70-150 mm gravel and pea gravel. On top of the pea gravel a 100 mm layer of wood shavings, which had been soaked for 2 days was added, this formed the bedding layer for the worms.

A vertical divider was placed in the vermifilter to subdivide the area in the ratio 90:10, to allow the system to stay aerobic when the 90% area was covered in sludge. Initially the vermifilters were seeded with different masses of worms (Table 1) and numbers of cocoons in order to study the impact of worm density on the systems. The numbers of cocoons were estimated to give an equivalent range of worm densities once they had hatched and reached maturity (Table 1). On Day 21 an additional 50 g of worms were added to all of the vermifilters that were originally seeded with worms which is explained later in this paper.

Table 1. Initial worm and cocoon density

V	Worm/cocoon density (mass or number added)	V	Worm/cocoon density (mass or number added)
1	0 (control)	10	0 (control)
2	0.5 kg/m^2 (50g)	11	0.5 kg/m^2 (50g)
3	1 kg/m^2 (100g)	12	1 kg/m^2 (100g)
4	2 kg/m^2 (200g)	13	2 kg/m^2 (200g)
5	4 kg/m^2 (400g)	14	4 kg/m^2 (400g)
6	500 cocoons/m^2 (50 cocoons)	15	500 cocoons/m^2 (50 cocoons)
7	1000 cocoons/m^2 (100 cocoons)	16	1000 cocoons/m^2 (100 cocoons)
8	2000 cocoons/m^2 (200 cocoons)	17	2000 cocoons/m^2 (200 cocoons)
9	4000 cocoons/m^2 (400 cocoons)	18	4000 cocoons/m^2 (400 cocoons)

The vermifilters were fed with faecal sludge collected from pour-flush portable toilets that were being used on a construction site in Pune. As the faecal sludge had a high water content it was settled for 1 day, then the settled sludge was added to the system and the volume of sludge added was recorded. Three different batches of sludge were used throughout the experiment. *Sludge 1* was used from Day 2 to 5, *Sludge 2* was used from Day 6 to 8 and *Sludge 3* was used from Day 10 to 11. In total between 46 and 62 litres of sludge were added to the vermifilters (explained below). Each new batch of sludge was analysed for the following parameters: pH, total solids (TS), chemical oxygen demand (COD), faecal coliforms (FC) and *Ascaris spp*. number and viability. Additionally the effluent collected after the final feed and the vermicompost, which had developed by the end of the trial were tested for these parameters. Structured observations of the vermifilters were undertaken daily, and sightings of worms, cocoons and vermicompost were recorded.

At the end of the experiment the vermifilters were decommissioned. Within each layer the mass of worms and vermicompost was measured and the number of cocoons was counted. The vermicompost from each layer was then combined and a sample was sent for full analysis as mentioned previously.

Results and discussion

The experiment was run for a period of 52 days (7/3/15 to 27/4/15). The feeding phase took 11 days, leaving only 41 days for sludge digestion and vermicompost production. This was a relatively short period to run such an experiment as in previous work it was noted that it took approximately six weeks for the worms to acclimatise to a new food source (Furlong et al., 2014a).

The amount of feed was increased from two litres on Day 2 to four litres on Day 3, to eight litres per day for the subsequent five days (Day 8). Over this period the vermifilters were fed with a total of 46 litres of

sludge. On Day 8, eight litres of unusually thick sludge (from the scum layer) were added to V8 to V18. The thick sludge sat on top of the bedding layer, whereas previous sludge had entered this layer. This was of concern as it completely covered the bedding layer including the refuge area and this, coupled with the reduction of the air voids in the bedding layer caused by the thinner sludge, could easily have caused the vermifilters to go anaerobic. Worms were observed trying to escape these vermifilters at this point. Therefore on Day 9 some of the thicker sludge was removed and placed in the vermifilters with lower amounts of solids and the refuge areas were cleaned by rinsing with water. Due to this no further sludge was added to V17 to V18. Different amounts of sludge were then added to the other vermifilters, over the following two days to try to equalise the amount of feed in each system.

Worm health

During the first eight days of the feeding period it was noted that the worms were not trying to escape. This meant that the sludge was not toxic to the worms and the environment that was created in the vermifilters was suitable for worm habitation .When the entire surface became covered with thick sludge it was noted that some worms were trying to escape (Day 10), which was probably due to the systems going anaerobic. Worms were recorded in the vermifilters from Day 12 onwards. On Day 21 an additional 50g of worms was added to replace those that may have left. From Day 40 to Day 52 there were consistent sightings of worms in V2 to V5 and from Day 42 to the end of the experiment in V12 toV14. There were few sightings of worms in V11 during this period. This lag of consistent sightings of worms could be due to the impact of the addition of the thick sludge in V8 toV18.

In the vermifilters seeded with worms the first cocoon was spotted in V5 on Day 35, and from Day 38 onwards cocoons were spotted in V2 to V5. Cocoons were seen slightly later in the second series of vermifilters which contained worms. The first cocoon was spotted on Day 38 in V14, Day 40 for V12 and V14, but they were not spotted until Day 43 in V11. Again this may have been due to the impact of the addition of the thick sludge in V8 to V18. These were positive indicators of worm health and activity in these systems.

In the vermifilters that were seeded with cocoons worms were first spotted in V9 on Day 34, and by Day 43 worms had been seen in V6 to V9. Worms were sighted slightly later in the second set of vermifilters seeded with cocoons: they were seen in Day 48, but were only sighted in V16 and V17. This again is possible evidence of the impact of the thick sludge on the system.

During decommissioning the worms were only found in the bedding material or pea gravel layer. This means they were actively feeding and in contact with their food. The worm density in all vermifilters had significantly decreased from the start of the experiment (final average worm mass across all vermifilters was 46g). Because the surviving worms appeared healthy and vermicompost was being produced the drop in numbers was likely to be due to limited food supply and not any toxic effect. The worm population may have decreased in V8 to V18 due to the impact of the thick sludge; this was probably reflected in the lower worm masses in V11 toV14 (ranging from 28g to 35g) (excluding V13 = 41g) compared to V2 to V5 (ranging from 35g to71 g). The worm density in all of the vermifilters was very similar at the end of the experiment, which would suggest that this may either be the optimum worm density for these systems (0.5 kg/m^2) or that there was insufficient feed to sustain larger populations. This was supported by the fact that worms were trying to leave several of the vermifilters after Day 49. It should be noted it was difficult to determine if all the sludge had been consumed as it was mixed with the bedding material.

During decommissioning the numbers of cocoons were enumerated in the vermifilters initially seeded with worms. A higher than expected number of cocoons were found in the vermifilters (65 to 1,200) which indicates that this was a good environment for the worms as they only mate when conditions are favourable. Again higher levels of cocoons were found in V2 to V5 (ranging from 200 to 1,200) compared to V11 to V14 (ranging from 65 to 415), which would suggest that the thick sludge impacted the health of the worms. The cocoon numbers would also suggest that a higher worm populations were supported at some point during this experiment and the present low worm population might be driven by a lack of resources, i.e. food.

Although worms were sighted in the vermifilters seeded with cocoons (V6 to V9 and V15 toV18) a very low mass was recorded at the end of the experiment (1g to 8g). This could be attributed to the low weight of the juvenile worms which can weigh below 0.001g and the time taken to reach maturity (40 to 60 days for this worm species, (Edwards & Bohlem, 1997)). As juvenile worms are very small they may also have been missed during enumeration. What was surprising was that no residual cocoons were found. There are two possible explanations for this: they may have been missed due to their size during enumeration; this was

thought to be unlikely as the staff undertaking this task are experts in the this field; the second explanation was that all of the cocoons had hatched during the experiment and the worms are in a juvenile state.

Sludge

Sludge 1 had lower than expected COD and TS (Table 2), the expected range being from 1,200 to 50, 000 mg/l for COD and around 3% for TS (Niwagaba et al, 2015). *Sludge 2* was sent for analysis with effluent samples (Table 3) and although there was a clear visual difference in the sludge and effluent this was not reflected in the COD and TS results, which led to further samples (*Sludge 3*) being sent to another laboratory (Laboratory B, Table 2) for validation (COD and TS analysis only). From the results gained (Table 2) it can be seen that the COD and TS in the original samples (Laboratory A, Table 2) were lower by approximately a factor of 10. Both laboratories were questioned about the methods used, sample handling and dilutions, and both stood by their results and procedures. From these results it seems as if a dilution factor was not being accounted for in the data from the original laboratory (Laboratory A, Table 2).

Table 2. Sludge analysis

Parameter	Sludge 1a	Sludge 1b	Sludge 3a		Sludge 3b		Sludge 3c		Sludge 3d	Sludge 3e
Day	3		24						54	
Laboratory	A	A	A	B	A	B	A	B	A	A
pH	6.20	6.35							6.90	6.89
TS (mg/l)	1,428 (0.14%)	1,290 (0.13%)	1,824 (0.18%)	20,600 (2.1%)	1,752 (1.8%)	24,580 (2.5%)	1,840 (0.18%)	20,860 (2.1%)	2,136 (0.21%)	2,270 (0.23%)
COD (mg/l)	682	616	1,246	11,200	1,364	17,200	1,316	11,600	1,294	1,320
FC (CFU/100ml)	$49x10^6$	$58x10^6$							$15x10^6$	$58x10^6$
Ascaris spp (total eggs/g)	12	16							9	8
Ascaris spp viability (eggs/g)	4 (33%)	9 (56%)							2 (22%)	3 (38%)

Effluent quality

The effluent quality was only measured once during the study. The results from the effluent quality analysis can be seen above in Table 3. In terms of COD and FC they are within the range expected from previous work (Furlong et al., 2014 a,b). This also supports the theory that the problem with the sludge samples was due to a dilution factor not being taken into account. If it is assumed that this dilution factor is 10, which seems credible from the results discussed, then the following estimation of removal efficiencies seem valid: TS 90-93%, COD 89-94%, FC 90-99.9%, *Ascaris spp* 85-98%. When these removal efficiencies were explored there was no difference in the controls, those seeded with cocoons or worms, nor within the different densities. This suggests that the effluent was being treated by the filter media and there was no impact from the presence of worms.

Table 3. Results from sludge 2 and effluent analysis

V	pH	TSS (mg/l)	COD (mg/l)	FC (CFU/100ml)	*Ascaris spp* (eggs/g)	*Ascaris spp* viability (eggs/g)
Sludge 2	6.72	330	464	$26X10^6$	8	2
1	6.8	295	410	$15x10^6$	3	1
2	6.63	326	476	$12x10^6$	6	2
3	6.94	240	395	$9x10^6$	2	0
4	6.74	380	490	$22x10^6$	9	2
5	6.67	360	480	$14x10^6$	7	4
6	6.7	3.78	475	$9x10^6$	12	2
7	6.85	352	510	$18x10^6$	5	1
8	6.84	260	392	$8x10^6$	2	0
9	6.77	285	468	$12x10^6$	8	2
10	6.8	278	488	$7x10^6$	8	4
11	6.62	205	516	$18x10^6$	10	4
12	6.54	306	485	$20x10^6$	9	3
13	6.92	212	320	$8x10^6$	2	0
14	6.98	230	346	$12x10^6$	4	0
15	6.65	248	256	$6x10^6$	8	1
16	6.87	216	296	$5x10^6$	2	0
17	6.3	305	402	$18x10^6$	4	1
18	6.49	320	416	$22x10^4$	10	7

Vermicompost and sludge

Vermicompost was first recorded in V3 on Day 27 and by Day 38 it had been recorded in V2 to V5. In the second set of vermifilters, vermicompost was not recorded until Day 37 in V14, then in V13 on Day 42. When the systems were decommissioned vermicompost was not found in any of the systems which were seeded with cocoons, but was found in all the systems which were seeded with worms. Vermicompost was only found in the bedding material, meaning the vermicompost was not moving through the filter.

The mass of the vermicompost generated did not vary across the systems (Table 4), so worm density did not have an impact on the amount of vermicompost produced. This may indicate that all of the sludge had been turned into vermicompost. This could not be verified as the sludge was mixed with the bedding material. This may be a further indication that the systems were underfed. When no vermicompost was present a sample of the bedding material that contained sludge was sampled.

If the analysis in Table 4 is correct it can be seen that both the faecal coliform numbers and the number of *Ascaris spp* eggs have decreased significantly compared with the original sludge results (Table 2). It was thought that *Ascaris spp* eggs would accumulate in the bedding layer and then the worms would consume them. What was unexpected was that this change occurred across the controls and the vermifilters seeded with cocoons. There does seem to be slightly lower number of *Ascaris spp* eggs in the vermifilters containing worms, but this difference was not very significant. From these results it looks like the conditions

generated in the system are able to reduce faecal coliforms and remove *Ascaris spp* eggs, but the mechanism is not yet known. In some cases the results meet the EPA condition for applying biosolids to land <1000 per g of TS dry weight of faecal coliforms and < 1 viable ova (egg) per 4 g of TS dry weight (EPA, 2003) . This would mean the health risk for handling vermicompost and reusing it is significantly reduced.

Table 4. Style: Vermicompost (VC) and sludge + bedding material (S) analysis

V	Mass of VC (g)	Sample type	TS (%)	COD (mg/l)	FC (CFU/100ml)	*Ascaris spp* (eggs/g)	*Ascaris spp* viability (eggs/g)
1	0	S	74.8	36,540	$4x10^2$	0	0
2	370	VC	74.2	34,960	$8x10^2$	1	0
3	483	VC	70.5	35,262	$6x10^2$	0	0
4	261	VC	72.6	34,830	$4x10^2$	0	0
5	451	VC	70.5	32,370	$2x10^2$	1	0
6	0	S	72.6	30,618	$6x10^2$	4	2
7	0	S	71.2	30,934	$4x10^2$	3	0
8	0	S	74.0	35,016	$2x10^2$	1	0
9	0	S	72.6	34,312	$8x10^2$	4	4
10	0	S	70.8	34,480	$4x10^2$	2	1
11	233	VC	75.3	36,210	$4x10^2$	6	2
12	247	VC	76.1	30,110	$2x10^2$	1	0
13	301	VC	72.6	32,624	$2x10^4$	0	0
14	422	VC	72.4	32,508	$5x10^2$	0	0
15	0	S	74.1	30,465	$2x10^2$	3	3
16	0	S	74.4	32,826	$4x10^2$	1	1
17	0	S	75.1	38,020	$8x10^2$	0	0
18	0	S	70.4	30,150	$2x10^2$	4	1

No undigested sludge could be recovered from the vermifilters, due to it being mixed with the bedding material. Therefore an attempt to estimate the solids conversion was made using the following assumptions; the solids content of the sludge was 2%, the volume of sludge added was 62 litres, the amount of vermicompost produced was 350g, the solids content of the vermicompost was 73%, and all of the solids were converted. Using these assumptions 1 kg of sludge was converted into 0.2 kg of vermicompost (dry weight). This conversion factor is very similar to those gained in our previous work on worm-based sanitation, where 1 kg of faecal sludge was converted into 0.09 and 0.2 kg of vermicompost (Furlong et al., 2014a,b).

Conclusions

Although this study was not completely definitive it has shown clearly that:

- worms are capable of digesting faecal sludge and converting it into compost
- cocoons can hatch into worms in the presence of faecal sludge

This is therefore a promising avenue for sludge treatment, which merits further examination, particularly over a longer period of time with more feed cycles. The difficulties encountered in obtaining reliable analyses of the sludge properties do not affect these overall conclusions, but do make it difficult to quantify the effectiveness of the treatment. It is likely, by comparison with previous work, that sludge digestion went to completion but further work is necessary to confirm this.

Acknowledgements

The authors would like to extend thanks the International Federation of the Red Cross and Red Crescent for funding this research. Primove Infrastructure Development Consultants PTV Ltd for hosting this research.

References

Eastman B. R., Kane P. N., Edwards C. A.,Trytek L., Gunadi B., Stermer A. L. and Mobley J. R., (2001).*The effectiveness of vermiculture in human pathogen reduction for USEPA biosolids stabilization*. Compost Science & Utilization, 9 (1) 38-49.

Edwards C. A. & Bohlem, (1997) *Biology and Ecology of Earthworms*. Chapman and Hall, London.

EPA (2003) Environmental regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge. United States of America Environmental Protection Agency.

Furlong C., Templeton M.R., Gibson W.T. (2014 a) *Processing of human faeces by wet vermifiltration for improved on-site sanitation.* The Journal of Water, Sanitation and Hygiene for Development. Vol 4, No 2, 231-239.

Furlong C., Gibson W.T., Templeton M. R., M. Taillade M., Kassam F., Crabb G., Godsell R., McQuilkin J., Oak A., Thakar G., Kodgire M., Patankar. R. (2014 b) *The Tiger Toilet: From Concept to Reality.* IWA specialist conference on Municipal Water Management and Sanitation in Developing Countries. AIT, Bangkok, Thailand.

Niwagaba C. B., M Mbéguéré M and Strande L. (2015) *Chapter 2: Faecal Sludge Quantification, Characterisation and Treatment Objectives in Faecal Sludge Management.* (Ed)Strande, L., Rontenltap, M. and Brdanovic, D., IWA Publications Ltd: London.

Contact details

Claire Furlong
WEDC, Loughborough University,
Loughborough, LE11 3TU, UK
Tel: +44 (0)7739080667
Email: c.furlong@lboro.ac.uk

Walter Gibson
Bear Valley Ventures Ltd, Braeside,
Cotebrook, Tarporley, CW6 0JH, UK
Tel: +44 (0)7805840358
Email: waltergibson@bearvalleyventures.com