
40th WEDC International Conference, Loughborough, UK, 2017**LOCAL ACTION WITH INTERNATIONAL COOPERATION TO IMPROVE AND SUSTAIN WATER, SANITATION AND HYGIENE SERVICES****Optimisation of faecal sludge processing via vermifiltration***Enrique Hernández, C. (Spain) & Furlong, C. (Netherlands)***PAPER 2833**

Faecal sludge requires treatment before it can be safely discharged. Novel treatment technologies, such as vermifiltration need to be explored. This study aims to determine if a simple vermifilter containing Eisenia fetida can process sludge and explores the effect of bedding materials (woodchip, granular activated carbon (GAC) + woodchip, and clay pebbles + woodchip) on nitrogen reduction in the effluent. All bedding materials performed well for general effluent quality, but nitrification was not found to occur. This was thought to be due to sampling and analysis techniques. The GAC bedding was unsuitable as worm density decreased. The optimum bedding material was woodchip which yielded the highest worm and cocoon densities, vermicompost production and solids conversion. This study proves that E. fetida have the ability to process sludge in a simple vermifilter and adds to the debate on nitrification in these systems.

Introduction

Worldwide, 2.7 billion people rely on onsite sanitation (OSS) (Strande, 2014). The partially treated or stored material that accumulates in OSS systems is known as faecal sludge (FS), this needs to be safely managed to avoid health and environmental impacts. Faecal sludge management encompasses several steps; containment, emptying, transportation, treatment, reuse and/or disposal. This system is known as the sanitation service chain. FS is a difficult material to treat due to its highly variable characteristics. These variations are caused by factors such as technology type, how it is used, emptying method and frequency (Niwagaba *et al.*, 2014). For instance, pH can range from 1.5 to 12.6, ammonium-nitrogen from 150 to 5,000 mg/L, and nitrates from 0.2 to 21 mg N/L (USEPA, 1994; Koné & Strauss, 2004; Kootatp *et al.*, 2015). Traditionally, FS is treated using drying beds or planted systems (Tilley *et al.*, 2014). These systems require a large amount of space, are labour intensive, the effluent requires further treatment, and they are generally centralised meaning they have high transport requirements (Tilley *et al.*, 2014).

The use of vermifilters may provide an innovative treatment solution for FS, enabling small decentralised modular treatment centres to be built, which would be both sustainable and resilient. A vermifilter is a biological filter containing composting worms (worms which feed on organic matter) (Sinha *et al.*, 2010). Most vermifilters include a bedding layer, which is a supporting matrix for worms and filters out solid particles. Worms ingest these particles and convert them into vermicompost (worm excreta), thereby promoting organic degradation and stabilisation (Garg *et al.*, 2006). Simultaneously, micro- and macro-organisms, biofilms and other removal mechanisms, such as adsorption by the bedding layer, add to this process. Vermifilters are aerobic, therefore ensuring an odour-free process (Sinha *et al.*, 2010). The most common worm species used is *Eisenia fetida*, which are capable of processing sewage sludge using traditional vermicomposting techniques (Eastman *et al.*, 2001) and in vermifilters (Xing *et al.*, 2012).

A simple vermifilter has been used successfully to treat fresh human waste *in-situ* (Furlong *et al.*, 2016). This design was then adapted to treat faecal sludge. However, this study was limited, due to problems with the analysis and a lack of effluent samples (Furlong *et al.*, 2015). The general conclusions drawn from this proof of concept study was that worms could digest faecal sludge (Furlong *et al.*, 2015). A major issue in these systems is that nitrification occurs, due to their aerobic nature (Furlong *et al.*, 2014). This can lead to

environmental and health problems, such as eutrophication and blue baby syndrome (Mahvi *et al.*, 2005; WHO, 2011).

The aim of this study was to build on the work of Furlong *et al.* (2015) and to determine if worms can treat faecal sludge and to explore the use of different bedding materials to reduce nitrogen levels (specially nitrates and nitrites) in the effluent.

Methodology

Three bedding materials were chosen: woodchip, granular activated carbon (GAC) and clay pebbles. Woodchip was used as a control, as other studies demonstrated its suitability (Furlong *et al.*, 2014). GAC was chosen as it has the potential to adsorb nitrates and nitrites (Kinoshita & Mihara, 2010), but has never been used as bedding material. Clay pebbles have not been assessed for nitrogen removal, although they are known to reduce suspended solids and chemical oxygen demand (COD) (Zhao *et al.*, 2010).

Feed sewage sludge (a mixture of primary and secondary sewage sludge) was used as a proxy for FS, as FS was not available. The characteristics of the sewage sludge were found to be comparable FS (Enrique Hernández, 2016).

Experimental set-up

Six vermifilters (V1 to V6) were constructed of two plastic boxes (surface area of 0.09m² and depth 22.5cm). Bedding layers and *E. fetida* were placed in the upper box, which had its base drilled with holes. The bottom box acted as a sump for effluent and contained a tap. Experimental set-up can be seen in Enrique Hernández (2016). All vermifilters (VFs) had an initial worm density of 2kg/m² and all bedding layers were 10cm deep (Furlong *et al.*, 2014). The bedding layer matrices were: V1 and V2 woodchip (Wc vermifilters); V3 and V4 woodchip and clay pebbles in a 1:1 volumetric ratio (Cp vermifilters); V5 and V6 woodchip and GAC in a 1:1 volumetric ratio (Ac vermifilters). The experiment was divided in 3 phases: Phase 1 (1 week): 100ml sludge/day + 1L water/day; Phase 2 (3 weeks): 200ml sludge/day + 1L water/day; and Phase 3 (4 weeks): 300ml sludge/day + 1L water/day. Water was sprinkled manually over the upper box to maintain the correct moisture levels. Feed was increased depending on the worms' capacity to process sludge. The experiments ran for 62 days.

Data collection

Sludge was characterised when each new batch arrived. Effluent data was collected once a week and tested. Vermicompost was characterised at the end of the experiment. All samples were tested for total solids (TS), ammonium (NH₄⁺), nitrates (NO₃⁻), nitrites (NO₂⁻), soluble chemical oxygen demand (SCOD) and *Escherichia coli* (Enrique Hernández, 2016). Effluent reduction efficiency, sludge mass reduction (wet) and solids conversion were calculated (Furlong *et al.*, 2014). All VFs were visually monitored daily for worm and vermifilter health (worm activity, cocoon production, odour and presence of fungi & flies). Final worm mass and density were calculated and cocoons were counted. Effluent quality is reported as weighted averages across the phases, due to it being more representative. The data was explored using One-Way ANOVA with a post-hoc Tukey in SPSS Statistics 19.

Results and discussion

The final amount of feed added to each vermifilter was 9.5 L. Unusually high SCOD values were detected in 12 samples and in other projects' samples. After investigation, it was concluded that the reagents were faulty, therefore these results were removed from the analysis.

Effluent quality

The effluent quality reduction efficiencies can be found in Table 1.

Total Solids (TS)

All VFs were highly efficient at reducing TS (98-99%, Table 1). There is little reported data on TS reduction in VFs, as total suspended solids (TSS) are generally reported. It should be noted that the TSS reduction efficiency in other VFs treating sewage sludge are lower (23%-83%, Xing *et al.*, 2012; Ma *et al.*, 2016; Xing *et al.*, 2016) than the TS reduction efficiency found in this study. This could be attributed to the configuration of the VF or the characteristics of the sludge.

SCOD

SCOD reduction efficiency in the VFs ranged from 96% to 99% (Table 1). This is higher than in a study that used a ceramsite VF to treat sewage sludge that reported COD and SCOD reduction of 49-54% and 73-87% (Zhao *et al.*, 2010). Most other studies analyse COD and have reported higher COD reduction efficiencies than Zhao *et al.* (2010). Furlong *et al.* (2014) reported 86-87% reduction when treating fresh human faeces and estimated COD reduction of 89-94% for faecal sludge (Furlong *et al.*, 2015) using a similar VF.

Ammonium

The ammonium reduction efficiency ranged from 98% to >99% across the vermifilters. This is higher than those reported in a multi-layer vermifilter treating faecal sludge, which achieved 49% reduction (Adhikari, 2015). The higher reduction may be due to the bedding material, considering that Adhikari (2015) used non-activated charcoal and woodchip.

Nitrates

Nitrate reduction in the Cp and Wc vermifilters were similar (97% and 96%, Table 1). The Ac vermifilters reduction efficiency decreased across the three phases (Table 1), which may be due to a decrease in the GACs ability to absorb nitrate as the experiment progressed. These results contradict the findings of others that have recorded an increase in nitrate linked to nitrification and aerobic conditions (Furlong *et al.*, 2014, Adhikari, 2015). The difference in these results is unlikely to be due to the bedding material as Furlong *et al.* (2014) also used woodchip, but are probably due to differences in sampling and analysis techniques (Enrique Hernández, 2016).

Nitrites

Nitrite levels initially increased during Phase I across all vermifilters, indicating that nitrification was occurring (Table 1). It was then removed during Phase II and III in Wc and Cp vermifilters. As with nitrates, this contradicts the findings of other authors and was possibly due to sampling and analysis methods. In the Ac vermifilters the nitrite levels continued to increase during Phase II and then decreased, possibly indicating the onset of anaerobic conditions in these vermifilters.

E. coli

The *E. coli* reduction efficiency was similar across all VFs concentrations across the experiments (93-99%, Table 1). Similar VFs reported higher reduction efficiencies of thermotolerant coliforms up to 99.9% in fresh faeces and estimated similar reduction rates in faecal sludge (Furlong *et al.*, 2014; Furlong *et al.*, 2015). Adhikari (2015) reported a 99.9% *E. coli* reduction in FS. These differences could be due to the feeds, initial *E. coli* concentrations, bedding material and depth, temperature, hydraulic loading and other factors.

Table 1. Reduction efficiencies (%) for each vermifilter				
Parameter	Phase	Wc	Cp	Ac
TS	Weighted average	98±0	98±1	99±0
SCOD	Weighted average	96±2	96±3	99±0
Ammonium	Weighted average	98±1	99±1	>99±0
Nitrate	Weighted average	96±1	97±1	79±10
Nitrite	Phase I	-344	-264	-383
	Phase II	35	50	-118
	Phase III	54	78	62
<i>E. coli</i>	Weighted average	95±8	93±6	99±2

Processing capacity and sludge wet mass reduction

The Cp and Wc vermifilters processed 3.33 L of sludge per m² of vermifilter, this capacity was higher than in similar vermifilters processing fresh human waste (approx. 2 L of sludge per m² of vermifilter (Furlong *et al.*, 2014, 2015). This was possibly due the sludge having a lower solids content and already being partially stabilised.

The Cp vermifilters (92%) performed slightly better than Wc and Ac vermifilters (91% and 79%) at sludge mass reduction (statistically they were not different). These results were in-line with the levels found by other researchers, e.g. 97% to 100% in vermifilters treating fresh human waste (Furlong *et al.*, 2014).

Vermicompost

The results from the vermicompost analysis can be found in Table 2. The highest mass of vermicompost was produced in the Wc vermifilters. Comparing Tables 2 and 3, these vermifilters had the highest worm mass and cocoon numbers, hence worm activity, meaning that Wc was the most conducive environment tested for *E. fetida*.

The levels of ammonium in the vermicompost (Table 2) were similar to the levels that El-Haddad *et al.* (2014) found in vermicompost from traditional processes, which ranged from 19 to 40 mg/kg. Ammonium levels are known to be dependent on the type of organic waste (El-Haddad *et al.*, 2014), hence it was assumed that they would be consistent in the vermicompost in all the vermifilters. Ac and Wc vermicomposts had higher ammonium concentrations compared to Cp vermicomposts (Table 2), which was thought to be due to the clay pebbles cation-exchange capacity.

The nitrate and nitrite levels across vermicomposts were similar, showing that the bedding material had little impact on these parameters. Nitrate concentrations in this study were found to be 4-5 times higher than the nitrate content reported by Khan & Ishaq (2011).

SCOD and TS were highest in Ac vermicompost, which could be related to the presence of undigested sludge (Table 3). Xing *et al.* (2012) reported higher SCOD in vermicompost (between 4,980-6,900mg/kg), which possibly indicates that the vermicompost in this study is more stabilised. *E. coli* loading was significantly higher in Cp vermicomposts. It is hypothesised that this was due to the bedding layer, which may be preventing the *E. coli* from dying off.

Table 2. Vermicompost production and characterisation			
	Wc	Cp	Ac
Vermicompost (g)	821±301	456±2	33±47
SCOD (mg/L)	2,350±281	2,500±89	4,500±2,500
TS (%)	21±0	21±1	35±1
Ammonium (mg/L)	31±3	12±4	33±0
Nitrate (mg/L)	33±1	38±4	41±2
Nitrite (mg/L)	8±2	5±1	6±0
<i>E. coli</i> (CFU/100ml)	406,800±159,273	1,649,800±817,983	203,400±22,600

Worm health

Although Ac vermifilters performed well for effluent quality, the bedding material was found to be an unsuitable environment for *E. fetida*, as worm mass and density decreased over time due to mortality (Table 3). This was thought to be due to the coarse texture of the GAC, which may damage the worms' skin.

Wc vermifilters showed the healthiest worm population (Table 3). This affects sludge mass reduction, vermicompost production and solids conversion, as they depend on worm activity. The doubling of worm mass over a 62-day period was quite unexpected, as other studies have achieved this increase over significantly longer periods. Furlong *et al.* (2014) found the worm mass increased by 114% to 262% over

365 days in vermifilters treating fresh human waste. While another study hypothesised that the optimum worm density in a vermifilter treating faecal sludge was 0.5 kg/m², as worm densities decrease to this level (Furlong *et al.*, 2015). The increase in worm density was most probably due to the feed type.

The Wc vermifilter had the highest solids conversion rate (Table 3), which was due to the conducive environment created for the worms (Table 3). The wet conversion for fresh faeces was found to be between 11% to 18% in Furlong *et al.* (2014), which is similar to the results in Table 3. The differences are most probably due to the feed or length of the study. A lower conversion rate would mean that the vermifilter would need to be emptied less frequently.

Table 3. Worm health across vermifilters			
	Wc	Cp	Ac
Worms (g)	359±29	314±51	146±62
Worm density (kg/m ²)	4.0±0.3	3.5±0.6	1.6±0.7
Worm mass increase (%)	100±16	75±28	-19±35
Cocoons	479±47	367±80	42±32
Wet Solids Conversion (%)	10±3	5±0	0.4±0.6

Conclusion

Although the three bedding materials had very different properties, the effluent reduction efficiencies were very similar. It was surprising that nitrification was found not to occur, which was thought to be due the sampling and analysis methods used. The Ac vermifilter proved to be a hostile environment for the worms, leading to high levels of worm mortality. The control vermifilter, which used a bedding matrix of woodchip, proved to be the most conducive for worm health and effluent quality. This research has proven that simple vermifilters containing *E. fetida* and with bedding matrices of Wc and Cp have the capacity to process 3.33 L of sludge per m² of vermifilter per day. Further research is required to optimize the solids processing capacity to make this a viable treatment for FS.

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