

Can Earthworms De-Clog Sand Filters?

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Abstract

Two species of earthworms, *Lumbricus terrestris* and *Eisenia fetida*, were used to de-clog sand filters purifying domestic sewage. The experimental set-up consisted of 6 filtration columns (4 research filters and 2 control filters) filled with fine sand ($d_{60}=0.2$ mm, $d_{10}=0.1$ mm). The sewage parameters at inflow to the filters were typical of the septic tank effluent. The filters were fed about 5.5 dm³/day at average doses of 31 cm/d. The TSS cumulative loading after three months was equal to 931.9 g/m². At the start of filter operating the average outflow of filters was equal to 105.6 cm³/min; at the end (except for filter Nos. 2 and 6) it was 0.3 cm³/min per filter and the clogging was achieved. A significant increase in outflow rates was observed two weeks after the application of worms, and it was equal to 94.7±2.9 cm³/min on average (average value for control filters: 7.1±0.8). The content of organic matter in the clogging layer of filters 4 and 5 was equal to 9.6±0.5 mg of dry mass per 1 g of sand, on average, and was significantly lower than the content of organic matter in the clogging layer of control filters (28.2±1.0 mg dry mass per 1 g of sand). There was no difference between control and research filter treatment efficiency (COD and NH₄-N). Four months after the worm application, the increase in average outflow from research filters was still observed, thus the de-clogging effect had been observed as long as the worms were alive.

Keywords: earthworms, de-clogging, septic tank effluent, sand filter

Introduction

Earthworms (eg. *Lumbricus terrestris*, *Eisenia fetida*) have been used for many years for sewage sludge [1], waste sludge [2], and organic waste [3] decomposition and composting. In recent years further studies on other groups of worms, for example sand worms (*Oligochaeta*), have been carried out to elucidate their impact on sand filter sediments and structure. Other research, related to the impact of worms on the pollutant concentration in wastewater, was conducted by Taylor et al. [4]. The studies on earthworms' impact on wastewater sludge and organic wastes were made in laboratories, in the field, and at technical scale.

Earthworm utilization for biomass decomposition is related to their ecology, especially specific breeding behavior (a relatively large amounts of mass of soil and biomass passes through their alimentary canal). There are some other features related to possibilities of their wider utilization:

- some earthworms can withstand periods of more than 5 days under anaerobic conditions or very low DO concentrations [5] due to high concentrations of hemoglobin in their blood (e.g. *Lumbriculus variegatus*)
- earthworms can decompose even slowly biodegradable material such as cellulose
- these organisms make the soil or other substratum less dense and improve percolating conditions

The last feature could be potentially used for de-clogging or clog prevention, but until now only a few related

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studies have been carried out [6, 7]. On the other hand, there are some limitations of worms' utilization to waste and wastewater decomposition. One of the most important is the toxicity of ammonia in its unionized form [8]. LC50 values (lethal concentration for 50% of the worms) range from 0.29 to 1.20 g/m³ NH₃-N for *L. variegates* [9]. Another well known *Lumbricus terrestris* survival limitation is the shape of filtering material grains. Sand grains of sharp shapes can be a danger to soft inner surfaces of their alimentary canal.

Some other conditions related to the worms' impact on hydraulic conductivity and soil porosity (in terms of high contamination, oxygen limitation, or sewage permanent stagnation) are important for their potential use, but still insufficiently known. To verify earthworm feasibility for de-clogging sand filters treating septic tank effluent, the experiment was carried out as described below.

Methods

Clogging Achievement

The experiment lasted 6 months. During the first 3 months septic tank effluent application was maintained to achieve clogging. The filters were fed about 5.5 dm³/day on average (31.1 cm/d). The total suspended solids (TSS) concentration in septic tank effluent was equal to 34.8±5.4 g/m³ (n=10). The TSS loading was equal to 10.84 g/m² per day.

After three months of operation at cumulative TSS loading up to 931.9 g/m², a significant decrease of filter flow was observed (from 105.6 cm³/min to 1.2 cm³/min on average), so the decrease in outflow rates was about of two orders of magnitude. The average outflow of filters, except filter Nos. 2 and 6, was much lower and was equal to 0.3 cm³/min per one filter on average. Sewage stagnation was observed on the sand surface of the filters, which was the effect of clogging (the inflow rate value was higher than the outflow one).

Experimental Setup

The experiment was carried out on a model consisting of 6 filtration columns (4 research filters and 2 control filters) filled with fine sand ($d_{60}=0.2$ mm, $d_{10}=0.1$ mm i.e. $UC=d_{60}/d_{10}=2.0$). The model was located in a manhole under ground surface. Research sand filters were made of PVC tubes (15 cm of inner diameter and 75 cm of height). The bottom of each filter had orifices of diameter 5 mm and was covered by geo-textile. The filters were filled with sand up to the 25 cm high.

Measurements and Analyses

Outflow was measured during 5 minutes from the start of dose application. Ammonium nitrogen (NH₄-N) was measured using a spectrophotometer. The same technique was used for COD measurements but samples were earlier

mineralized by heating (120 minutes) at 148°C. BOD₅ was analyzed using a respirometer. TSS were identified as a dry mass weight. Volatile suspended solids (VSS) were detected as a dry mass weight difference before and after incineration at 550°C for 2 hours [10].

Sewage Characteristics

The sewage originated from one household (a five-person family) and was treated in a septic tank. After filter clogging, 900 dm³ of the septic tank effluent was dosed once per day on each of the filters. Thus, the filter hydraulic load in this period was equal to 5.1 cm/d only. The inflow sewage parameters were typical for septic tank effluent: 34.8±5.4 g/m³ (n=5) for TSS, 62.5±7.5 g/m³ (n=3) for BOD₅, 122.8±8.7 g/m³ (n=5) for COD, and 39.7±3.5 g/m³ (n=5) for NH₄-N.

Earthworm Species Used

Two species of earthworms were used: *Lumbricus terrestris* and *Eisenia fetida*. Two different species were used due to their different ecologies: *Lumbricus terrestris* can potentially improve sand porosity by making holes and improving oxygen penetration (supply), and *Eisenia fetida* can accelerate the mineralization of organic matter. Twenty individuals were applied to each of four experimental filters. *Lumbricus terrestris* were applied to filter Nos. 4 and 6, *Eisenia fetida* – to filter Nos. 3 and 5. The concentration was equal to 3 individuals per 1 kg of dry sand.

Under laboratory conditions *Lumbricidae* can survive about 4 (*Eisenia fetida*) to 6 (*Lumbricus terrestris*) years [11]. Their potential life-span under field conditions is 4-8 years.

Results and Discussion

The Clogging State Achievement

The clogging state was achieved at cumulative TSS loading equal to 931.9 g/m². This value was similar to the value obtained during a previous study was carried out using the same source of pretreated sewage and the same type of sand in filters [12]. In that study, the significant decrease in permeability (from 43.3 cm³/min to 6.9 cm³/min) was achieved at about 855.1 g/m² cumulative TSS loading. The faster permeability decrease in this study (about one order of magnitude – from 105.6 cm³/min to 1.2 cm³/min on average) was probably related to the larger volume of daily dose (5.5 dm³) and its only once per day application (in previous study 0.48 dm³ of sewage was dosed three times per day). The sand used in the previous study was washed with 7% H₂O₂ solution, and the sand used in this study was not washed. Darby et al. [13] reported a similar clogging time – 70 days at very similar TSS and hydraulic loading rates (9.5 g/m² per day and 33.0 cm/d, respectively), for a sand filter with effective grain size, $d_{10}=0.29$ mm and COD influent concentration of 144 g/m³.

Impact of Earthworm Application on Filter Hydraulic Conductivity

The main aim of this research was to raise significantly the effluent value (if possible to the values observed at the start of experiment – before clogging) by earthworms and to achieve de-clogging.

After clogging, the sewage was removed from the surface of filters. Immediately after sewage removal, the worms were applied on the research filters' surfaces (filter Nos. 3, 4, 5, and 6). The significant increase in outflow rate was observed very soon – on the next day. The maximum values of sewage outflow rates were observed after two weeks (the average value was equal to $94.7 \pm 2.9 \text{ cm}^3/\text{min}$, $n=48$). At the same, time the average value for control filters (without worms) was equal to $7.1 \pm 0.8 \text{ cm}^3/\text{min}$, only ($n=24$). A little increase in permeability of control filters was caused by sewage removal and load decrease since the worms' application day. The worms' application influence on the outflow values is presented in Fig. 1.

The difference between outflow rates from experimental and control filters was confirmed statistically using

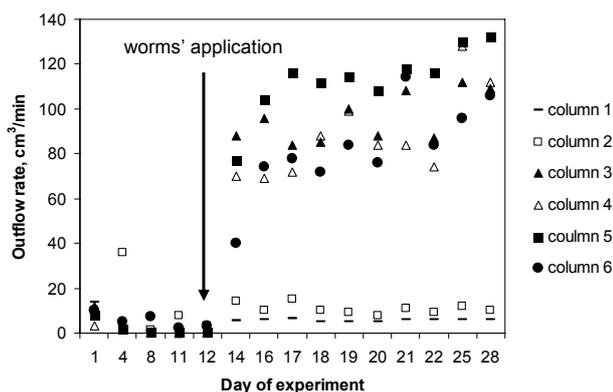


Fig. 1. Worms applying influence on the outflow values. Columns 1, 2: control filters (without worms), columns 3-6: research filters (with worms).

small-sample test of hypothesis for the difference in means (for filters of the smallest difference: column 2 and column 6, the statistics were equal to 10.97, for critical value equal to 2.26, $\alpha=0.05$ and $n=10$). Some observations on clogging prevention by worms were made during two other studies [6, 7], namely higher flows were observed in beds with worms than in beds without worms. It was not exactly explained in the papers, whether the lab-scale constructed wetlands were close to clogging state or not. No statistical verification of clogging prevention by worms was presented, either.

After three months new measurements of outflow rates were made. Relatively high flow values of research filters were observed, but they were significantly lower than three months earlier ($42.3 \pm 1.8 \text{ cm}^3/\text{min}$, $n=36$). Outflow rates from the control filters were similar to those observed three months earlier ($6.7 \pm 1.3 \text{ cm}^3/\text{min}$, $n=18$). The decrease in research filter capacity (from $94.7 \pm 2.9 \text{ cm}^3/\text{min}$ to $41.5 \pm 1.8 \text{ cm}^3/\text{min}$) was probably caused by much lower activity of worms (numbness) and some individuals' death (half of the population was still alive). These phenomena were obviously related to much lower temperatures in this period. The death of a part of the population could be caused by organic matter limitation (*Eisenia fetida*) and by the sharp shape of sand grains, as it is dangerous for *Lumbricus terrestris* due to their soft alimentary inner surface.

Organic Material Content in the Ground

A decrease in organic material content in the clogging layer of research filters was identified. The content of organic matter in the top two centimeters of depth of filter Nos. 4 and 5 was equal to $9.6 \pm 0.5 \text{ mg dry mass per 1 g of sand}$, on average ($n=5$). In the control filters the organic matter content was equal to $28.2 \pm 1.0 \text{ mg dry mass per 1 g of sand}$, on average ($n=3$).

The difference between column 1 and column 4 means was statistically confirmed (the statistics equal to 6.41 for critical value equal to 2.45, for $\alpha=0.05$ and $n=8$). This effect

a)



b)



Fig. 2. Surface of control filter No. 2 (a) and research filter No. 5 (b).

Table 1. Impact of worms' application on sewage treatment efficiency (data from 18.07, 21.07, 22.07, 24.07, 26.07).

Parameter	COD		NH ₄ -N	
	Control filters	Research filters	Control filters	Research filters
Inflow, mg/L	122.8±8.7 (n=5)		39.7±3.5 (n=5)	
Outflow, mg/L	66.4±6.7 (n=9)	64.8±4.7 (n=20)	26.1±3.0 (n=10)	28.0±2.6 (n=20)
Efficiency, %	44.3±5.0 (n=9)	47.3±3.5 (n=9)	33.8±7.6 (n=10)	29.2 ±6.7 (n=20)

was visually identified too (Fig. 2). The surface of the sand in the research filters was brighter and the structure was more porous than the surface of control filters. Better results (higher flow values and visually observed porosity) were obtained for filters with *Eisenia fetida* than for filters with *Lumbricus terrestris*, but the differences were not confirmed statistically. It could be interesting to carry out an experiment with the use of mixed *L. terrestris* and *E. fetida* populations. Probably, individuals of the first species would make the sand more uniform with depth and more porous and individuals of the second species would decompose and mineralize organic matter accumulated in the upper layer. So the mixed population could give better results.

TSS accumulation rates in the control filters were comparable to some other results of studies. Rinck-Pfeiffer et al. [14] observed about 11 mg of dry biomass per gram of dry soil. Other authors reported a wide range of biomass accumulated in the clogging layer, e.g. Kwanishi et al. [15] found in the upper layer (0-3 mm) of andosol a concentration of organic matter between 15 and 30 mg/cm³. The variable amounts of accumulated matter observed in a clogging layer are related to the influence of various conditions (hydraulic and contaminants loading, type of soil, frequency of dosing, temperature).

The Impact of Earthworms on Sewage Treatment Efficiency

Treatment efficiency was investigated in relation to COD and NH₄-N only, because the aim was not to identify treatment efficiency of sand filters as a whole (it was investigated during previous studies [12, 16]), but to verify the impact of the worms' application on treatment efficiency. The results of sewage treatment efficiency of control and research filters are presented in Table 1.

There was no significant difference between control and research filter efficiency (for COD the statistic was equal to 0.19 for critical value equal to 2.05 and $\alpha=0.05$). The relatively low efficiency of either control and research filters was related to the small height of filters (25 cm only), short duration time (the clogging process proceeded in duration of start-up period), and low temperature before the worm application (below 10°C on average). Similarly low efficiency removal values (42.4-64.8% for TKN), comparable to the values obtained during this research, were presented by Nakhla and Farooq [17], but for deeper filters (50 cm) and at much lower pollutant concentrations (41 g/m³ for COD and 3.2 g/m³ for TKN) in the applied sewage.

Conclusions

The results of this study showed that both species of earthworms can be used for de-clogging. The following conclusions were drawn:

- The application of worms caused a fast rise in outflow rates, the maximum values of sewage outflow rates were observed after two weeks, and they were higher than the control filters average value by one order of magnitude.
- The de-clogging effect was manifested by a decrease in matter accumulation in clogging layers and visually observed increase in upper layer porosity.
- Once applied, worms survived more than 4 months under typical operational conditions.
- After almost 4 months the increase in average outflow rate from research filters was still observed (seven times higher than the outflow rate from control filters).
- The de-clogging effect (significant increase in outflow rates comparable to the values noted at the start of operation) can be observed as long as the worms are alive.
- An early application of worms (before clogging occurrence) can probably prevent filter clogging, as reported by other authors [6, 7].

There is a need for making further studies to verify survival length of worms, unclogging period duration, and the possibility to use other worms, such as sand worms or aquatic worms, or to use mixed populations. The need for wastewater removal from filter surface before worm application should also be confirmed. It seems that *Lumbricus terrestris* makes the sand more uniform in depth and more porous, while *Eisenia fetida* decomposes and mineralizes the organic matter accumulated in the upper layer. Thus the experiment with mixed populations could provide better results. A longer *Lumbricus terrestris* survival time could probably be achieved by the use of smooth grains in the filtering material.

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