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Septage unit treatment by sludge treatment reed beds for easy management and reuse: performance and design considerations

Boram KIM^{a,*}, Thomas BEL^b, Pascal BOURDONCLE^c, Jocelyne DIMARE^d, Stéphane TROESCH^e
and Pascal MOLLE^{a,*}

^a Irstea, Wastewater treatment team, 5 rue de la Doua, 69100 Villeurbanne, France

(E-mail: boram.kim@irstea.fr; pascal.molle@irstea.fr)

^b CCTVA, 370 Avenue du 8 Mai 1945, 82800 Nègrepelisse, France

^c SATESE 82, 19 rue du docteur Labat 82000 Montauban, France

^d Adour Garonne Water agency of, 90 rue du Férétra, CS 87801, 31078 Toulouse Cedex 4, France

^e Epur Nature – 12 rue Toussaint Fléchaire, 84510 Caumont-sur-Durance, France

* Corresponding authors

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Abstract

Sustainable treatment and management of fecal sludge in rural area requires adapted solutions. Rustic and simple operating processes such as sludge treatment reed beds (STRB) have been increasingly considered for this purpose. The biggest full scale septage treatment unit in France had been built in Nègrepelisse with the final objectives of reusing treated sludge and leachates for agriculture spreading and trees irrigation, respectively. The aim of this investigation was to validate the treatment chain of this installation. The obtained field data showed firstly that the overall removal efficiencies of STRB were satisfactory and stable. Removal rates higher than 98% for COD and SS and a bit lower for KN represented so far a beneficial septage treatment by STRB. The highlighted necessity of a suitable complementary leachate treatment (before tree irrigation) justified the presence of the second stage of vertical flow constructed wetland. The sludge deposit drying and mineralization efficiencies were on the right track. According to hydrotextural diagram analysis, surface deposit was however found to have high deformability probably due to the youngness of the installation. An in-depth understanding of STRB system needs continuous long-term studies. Further investigations would therefore be worth to evaluate sustainability of the whole installation.

Keywords

sludge treatment reed beds; septage; performance; leachate treatment

INTRODUCTION

Faced with the increase of septage flow in rural area (Troesch et al., 2009), which has been induced by the action of public services for non-collective wastewater treatment, sustainable treatments and managements of fecal sludge has become important for small communities in France. This need is also true for developing countries where latrines are widely used (Kengne et al., 2009). If conventional treatment technics rely on transporting septage to large wastewater treatment plants, they induce high costs and environmental impacts due to liquid sludge transportations. In this context, rustic and simple operating processes such as sludge treatment reed beds (STRB, or sludge drying reed bed) have been increasingly considered as adapted solutions (Kengne et al., 2009; Paing and Voisin, 2005; Troesch et al., 2009; Uggetti et al., 2009; Vincent et al., 2011; Vincent et al., 2012) to provide dedicated optimum septage treatments units nearby fecal sludge production areas. Previously initiated for activated sludge volume reduction in Denmark since 1988 (Nielsen, 1990), the STRB system has proven its sludge treatment efficiency (Nassar et al., 2006; Nielsen, 2007; Obarska-Pempkowiak et al., 2003; Troesch et al., 2009; Uggetti et al., 2009), allowing long-term sludge reduction via dewatering and mineralization processes. Since the early 1990s in France (Liénard et al., 1995), the use of STRB has been progressively adapted for septage treatment (Troesch et al., 2009; Vincent et al., 2011; Vincent et al., 2012). Several French research programs carried out during recent years (2007-2012) have proposed suitable design, operation and management rules for the septage treatment by STRB (Molle et al., 2013). However, a few full scale systems have been monitored in France, as well as design and operating rules need to be validated.

A full scale STRB unit treating $11,000 \text{ m}^3 \text{ y}^{-1}$ of septage has been built in Nègrepelisse (south of France) with final objectives of reusing treated sludge and leachates for agriculture spreading and trees irrigation (poplar and eucalyptus used for the municipal heating system), respectively. This septage treatment unit has been implemented on the basis of design rules established on pilot scale experiments (Troesch et al., 2009; Molle et al., 2013). Such installation is the biggest trial in France

representing an ecological solution for satisfactory local treatment of fecal sludge and appropriate reuses of residual products. It needed therefore investigations to validate the treatment efficiencies and precise operation modes. For this purpose, this treatment plant was monitored since its inception with a focus on: (i) fecal sludge characterization, (ii) performance assessment (septage by STRB and leachate by VFCW) and (iii) sludge deposit evolution (dewatering, mineralization and hydrotextural properties).

MATERIALS AND METHODS

Description of the treatment plant

Installation. The full scale STRB unit located in Nègrepelisse (Tarn-et-Garonne, France; Figure 1, Table 1) has been in operation since the end of 2013. It can receive up to 131 t of SS per year. This treatment capacity corresponds to 3500 emptied septic tanks per year. The treatment line consists of: (i) a stone trap followed by an automatic screening (10 mm mesh), (ii) an emptying tank (20 m³), (iii) an aerated buffer tank (capacity of 180 m³), (iv) 8 sludge treatment reed beds planted with *Phragmites australis* (325 m² each), (v) 2 vertical flow constructed wetlands (VFCW, 50 m² each) for leachates treatment and (vi) a treated leachate storage basin for irrigation (140 m³). In fact, the VFCW stage receives not only leachates but also a part of outlet effluent of a nearby wastewater treatment plant in order to have enough water volume for irrigation. To prevent clogging of the installation, the filter layer of the VFCW was composed of a mixture of sand (0/4 mm) and gravel (2/6.3 mm), with a d₅₀ of about 2 mm (Table 1).

Table 1. Particle size distribution of filter medium with depth in STRB and VFCW.

	Layer	Depth (cm)	Materials
STRB	Filtration	10	0/5 mm sands
	Intermediate	10	2/6 mm gravels
	Drainage	40	15/25 mm gravels
VFCW	Filtration	40	0/5 mm sands + 2/6.3 mm gravels
	Drainage	20	15/25 to 20/40 mm gravels

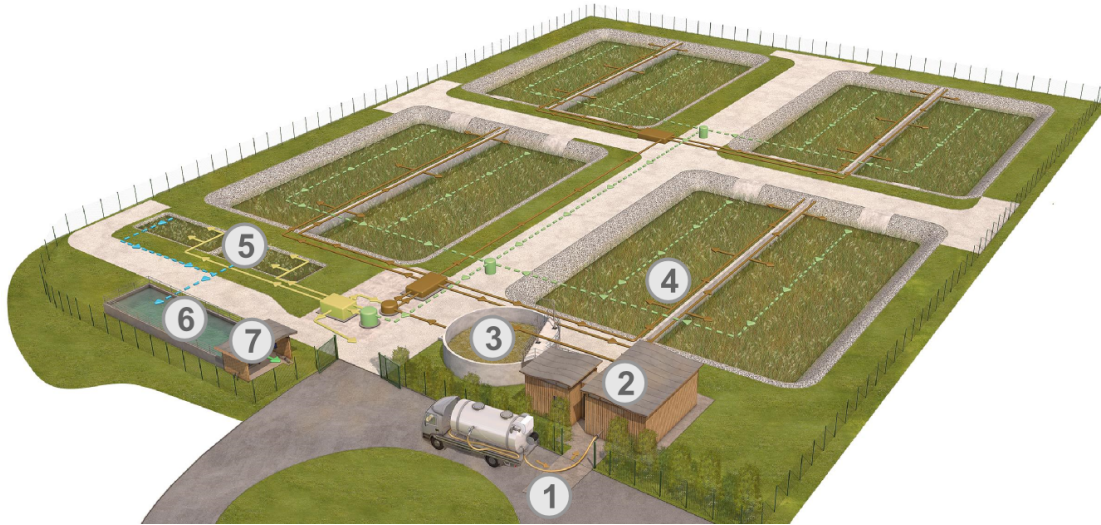


Figure 1. Schematic representation of the full scale STRB unit located in Nègrepelisse (Source: Epur Nature)

On-site equipment. Inlet flow was determined by measuring the functioning time of the pump whereas the outlet flows were measured by V channels equipped with pressure probes (STS) for STRB drainage and flow insert equipped with bubble flowmeter for VFCW drainage. The aerated buffer tank is equipped with pressure, SS and redox probes. Those continuous measurements allowed ensuring and controlling the qualitative and quantitative loads sent on STRB.

Functioning. For good acclimatization of reeds (October 2013), the whole installation was fed with low organic load (less than $20 \text{ kg SS m}^{-2} \text{ yr}^{-1}$) during the first six months. After this period, one year period was conducted from May 2014 with a sludge loading rate of $30 \text{ kg SS m}^{-2} \text{ yr}^{-1}$, 8-beds configuration and 1/7 days of feeding/resting cycles. Then, the load had been progressively increased until $40 \text{ kg SS m}^{-2} \text{ yr}^{-1}$ with 6-beds configuration and 3/15 days of feeding/resting cycles (summarized in Table 2). Only during irrigation periods (from May to September), the leachate of STRB was treated by one stage of VFCW and then sent via the irrigation network to a short rotation coppice (SRC, 3.2 ha planted of poplars and eucalyptus).

Table 2. Operation parameters, and sludge loading rates ~~and accumulation rate~~ during the commissioning (May 2014 – April 2015) and routine (May 2015 – Sept. 2015) periods.

Period	Number of beds	Feeding/resting period (d/d)	Hydraulic load (cm d ⁻¹)	Organic load (kg SS y ⁻¹)
Commissioning	8	1/7	6	24
Routine	6	3/15	11	37

Description of field monitoring campaigns

Regular campaigns. Since its inception, performance monitoring was conducted to evaluate the over-all performances of each treatment stage, a total of 44 regular campaigns were conducted with 24h time-proportional flow samplings. All samples were analyzed at the departmental laboratory (Tarn-et-Garonne) for the following parameters: total suspended solids (TSS), total and dissolved chemical oxygen demand (COD_{tot} and COD_{diss}), Kjeldahl nitrogen (KN) and ammonium nitrogen (NH₄-N) according to standard methods (APHA, 2005). Moreover, quantitative and qualitative measurements of sludge deposits were performed biweekly. Core samplings were conducted at 5 different points of the monitored beds at different distances from a feeding point. In addition to heights measurements of accumulated deposits, the 5 core samples were homogeneously mixed to obtain a composite sludge sample before the determination of the dry matter (DM) and organic matter (OM) contents according to the standard method (APHA, 2005).

Specific campaigns. Two specific campaigns were conducted in May and August 2015, in order to perform continuous measurements of nitrogen parameters in each processing step as well as follow the evolution of sludge deposits with resting time. Online monitoring of ammonium and nitrate nitrogen was carried out using ion specific probes (WTW VARION, with simultaneous compensation of potassium and chloride). In order to determine the mechanical and hydraulic properties of sludge deposit, hydrotextural diagram analysis was performed. Detailed methods are described in the work of Vincent et al. (2012). This measurement allows knowing from which DM

content the deposit behaves as a solid, i.e. when air enters into the matrix when drying.

RESULTS AND DISCUSSIONS

Influent fecal sludge characteristics

Physico-chemical characteristics of the incoming septage at Nègrepelisse are illustrated in figure 2. The incoming septage of the studied installation was found to be less concentrated than those from previous studies in France (Troesch et al., 2009; Vincent et al., 2011; Vincent et al., 2012). Indeed, the quality of septage had been known to have extreme variability depending on several parameters. Indeed, sludge quality depends on the practice of emptying (ex. frequency), the use of housing (i.e. primary or secondary residence), the type of septic tank (i.e. for all house wastewaters, flush tank, watertight tank, Imhoff, etc.).

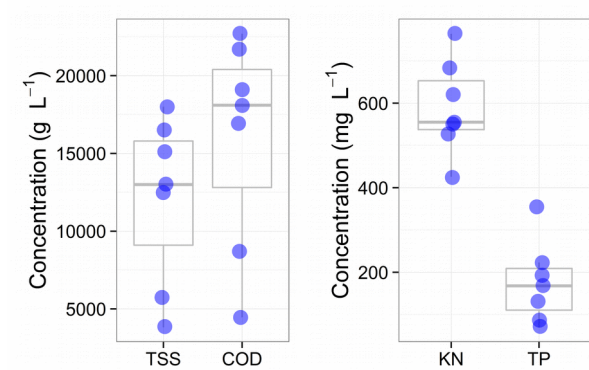


Figure 2. Physico-chemical characteristics of the incoming septage at Nègrepelisse.

Despite high concentration variations of incoming septage (Figure 2), the online measurement of TSS within the aerated buffer tank (Figure 3) confirmed its buffering role of TSS concentration (ranged between 10 and 20 g L⁻¹). The continuous redox potential measurement (Figure 3) confirmed that aeration allowed to avoid the installation of anaerobic condition (Eh maintained above 0 mV SHE) within the buffer tank. Particle size distribution analyses (results not showed here) showed that there was no other effects (ex. flocculation) of aeration on physical quality of septage.

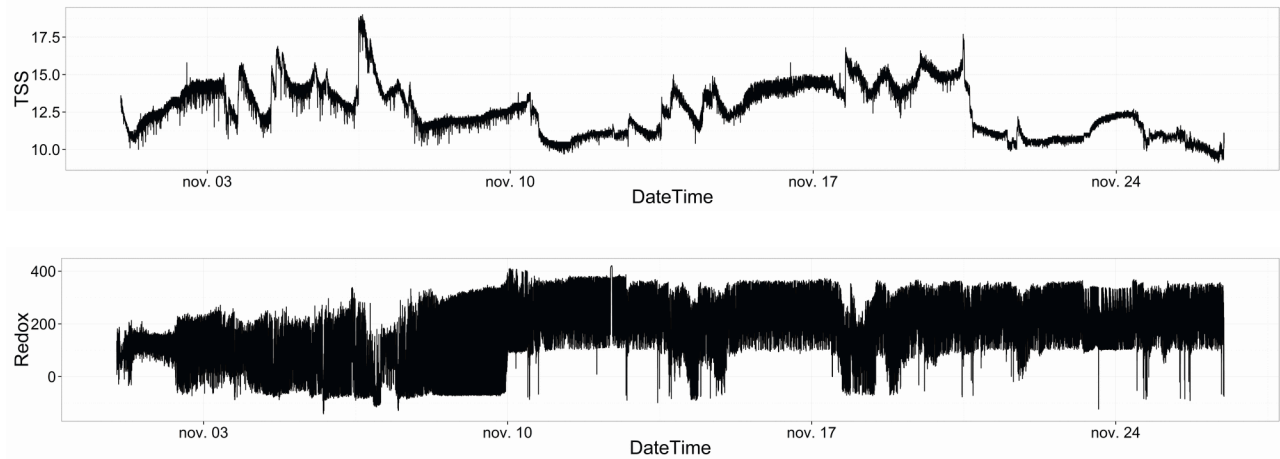


Figure 3. A monthly example (Nov. 2014) of continuous monitoring of TSS concentration and redox potential within the aerated buffer tank.

Effluent treatment

STRB performance. The data distribution curves of concentrations of different parameters at inlet/outlet of STRB are shown in Figure 4. Non negligible variations of inlet/outlet concentrations were noted (log scale of figure 3). The performance of STRB was found to be satisfactory from monitored commissioning period (load of $24 \text{ kg SS m}^{-2} \text{ year}^{-1}$) to loads of $37 \text{ kg SS m}^{-2} \text{ year}^{-1}$. The removal efficiency for TSS (99.5%) was excellent as well as for COD_{tot} (98.3%), KN (94.9%), and TP (94.8%).

Despite those good removal efficiencies, according to the characteristics of STRB leachate (Table 3), variations of STRB outlet concentrations were found to be important enough for COD_{tot} , KN and TP parameters (753 , 94 and 19 mg L^{-1} , respectively; Table 3), in which dissolved fractions are not negligible. The necessity to have further leachate treatment was therefore confirmed before tree irrigation. This justified the additional treatment of this leachate by VFCW.

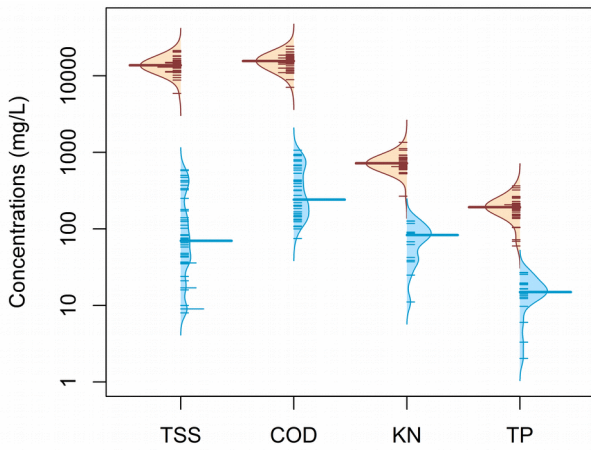


Figure 4. Distribution curves of different parameters monitored at inlet (brown, left) / outlet (blue, right) of STRB. The small and large bars correspond to individual data and medians, respectively.

Table 3. Concentrations (mean \pm std.) of monitored parameters at inlet/outlet of STRB.

Parameter	Inlet (mg L ⁻¹)	Outlet (mg L ⁻¹)	Removal efficiency (%)
TSS	14320 \pm 737	401 \pm 41	99.5
COD _{tot}	17168 \pm 457	753 \pm 39	98.3
DCO _{diss}	379 \pm 24	283 \pm 16	23.0
KN	742 \pm 26	94 \pm 8	94.9
NH ₄ -N	66 \pm 9	43 \pm 7	-
NO ₃ -N	0,4 \pm 0,1	37 \pm 12	-
TP	217 \pm 21	19,2 \pm 1,5	94.8
PO ₄ -P	1,6 \pm 0,7	5,9 \pm 0,7	-
SO ₄	55 \pm 4	89 \pm 6	-
Cl	251 \pm 27	218 \pm 14	-

Leachate treatment by VFCW

The mixture of leachates and treated wastewater is sent on VFCW stage with a mean hydraulic load of the order of 85 cm day⁻¹. The effluent characteristics at inlet/outlet of VFCW (Table 4) underlined a dilution of leachates by treated wastewater. Additional leachate treatment efficiencies by VFCW were also highlighted.

Table 4. Concentrations of monitored parameters at inlet/outlet of VFCW expressed as mean \pm SEM (Number of campaign).

Parameter	Inlet (mg L ⁻¹)	Outlet (mg L ⁻¹)
TSS	182 ± 22 (16)	90 ± 8 (16)
COD _{tot}	378 ± 31 (17)	232 ± 14 (17)
COD _{diss}	169 ± 12 (11)	127 ± 5 (11)
KN	46,9 ± 8,3 (10)	19,8 ± 3,2 (11)
NH ₄ -N	21,0 ± 3,9 (17)	8,8 ± 1,8 (17)
NO ₃ -N	55,6 ± 5,7 (17)	66,8 ± 5,0 (17)
TP	14,5 ± 1,0 (12)	13,6 ± 1,0 (14)

At the outlet of VFCW stage, observed TSS concentrations remained however non negligible, with a modest filtration performance (50%). TSS particles sizes arriving on the VFCW stage are relatively thin (80% of particles in a range of 5 to 80 µm). Granular size of VFCW filtration layer (d_{50} of about 2 mm) is slightly rough to ensure efficient filtration of fine particles. The sand particle size could be optimized in the future. Moreover, to improve the nitrification, it would be interesting to investigate the optimization of applied loads and / or filtration layer depth.

Sludge treatment

Dewatering and deposit mineralization

Regarding the sludge accumulation, after the commissioning period, about 10 cm per year of deposit accumulation was noted. Regular monitoring (Figure 5, a) also had showed a good behavior of the STRB. The average drying matter (DM) content was around 24% (± 4.6%). Two populations of DM contents, corresponding to seasonal variations, were noted. In summer, DM contents at the end of resting period were generally around 30%, but could sometimes be impacted by heavy rains and decreased to about 20%. In winter, DM contents were stabilized around 20%. Despite the youth of the installation (2 years), significant reductions of volatile organic matters (OM) contents from the incoming septage (72 ± 4% MES) to the deposit on STRB (64 ± 5% MES) confirmed a good mineralization of the deposit (Figure 5, b).

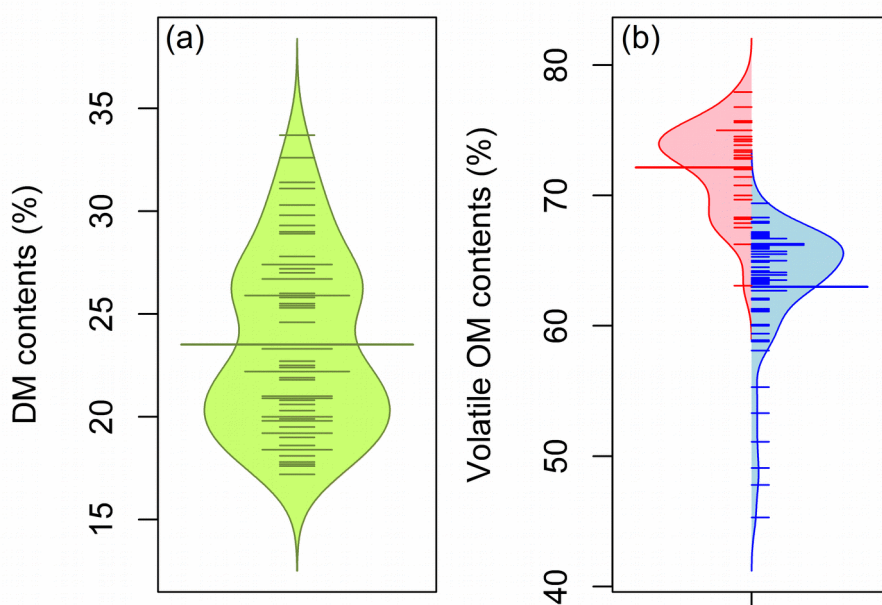


Figure 5. Data distribution curves: (a) dry matter (DM) contents of surface deposit of STRB, (b) organic matter (OM) contents relative to DM of incoming septage in aerated buffer tank (left) and surface deposit of STRB (right). Small and large bars correspond to individual data and medians, respectively.

Hydrotextural characteristic.

As Vincent et al. (2012) highlighted that hydrotextural properties of deposit did not depend on applied loads; hydrotextural diagram of studied installation was compared to the results from this previous study (Figure 6). The important data dispersion and low sample water contents (< 4 g/g, i.e. 20% DM) were in concordance with the referenced results (Vincent et al., 2012). The desaturation state, referred as “ideal shrinkage” (Ruiz et al., 2011), of surface deposit studied here was however difficult to observe (Figure 6), suggesting that studied samples presented higher deformability than the one observed by Vincent et al. (2012). This may be explained by: (i) the incoming septage characteristics (less concentrated) resulting in higher hydraulic load; (ii) the age of installation at sampling moments (17 months operation in this study compared to 50 months for referred study); (iii) the depth of deposit samplings (first 5 cm in this study compared to 10 cm for referred study).

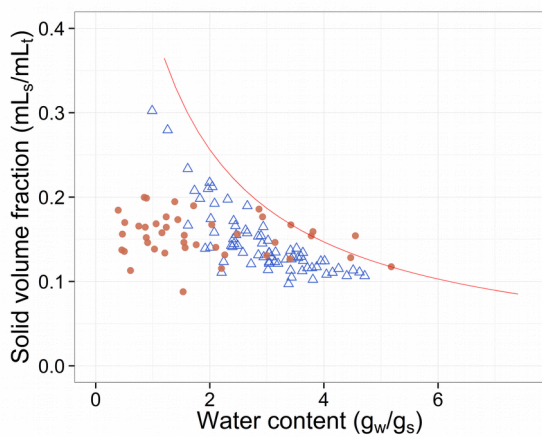


Figure 6. Hydrotextural diagram (i.e. solid volume fraction versus water content) for surface deposits of STRB (triangle points) compared with the reference values (round points) from Vincent et al. (2012). The red line represents theoretical desaturation curve for plastic materials.

CONCLUSION

The results shown in this study were obtained from field monitoring conducted during almost two years to evaluate the performance of STRB designed and operated for the treatment of the municipal septage collect of Nègrepelisse (France). The field data thus obtained showed firstly that the overall removal efficiencies of STRB were satisfactory and stable. Removal rates higher than 90% for COD and SS and a bit lower for KN represented so far a beneficial septage treatment by STRB, simple and easy to operate. The necessity of a suitable complementary leachate treatment was however highlighted (before tree irrigation), justifying the presence of the second stage of VFCW. The sludge deposit drying and mineralization efficiencies were on the right track. According to hydrotextural diagram analysis, surface deposit was however found to have high deformability probably due to the youngness of the installation.

As other constructed wetlands, an in-depth understanding of STRB system needs continuous long-term studies. Further investigations would therefore be worth to evaluate sustainability of the whole installation.

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