Particulate and dissolved phosphorus removal in agricultural drainage waters with a compact filter system

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Background

Phosphorus (P) losses through subsurface runoff from artificially drained agricultural fields contribute to local surface water eutrophication. Since subsurface drainage channels water flow into concentrated pathways, drainage filters present a potentially cost-effective, end-of-pipe solution to mitigate P losses. This study aimed at evaluating the performance of a compact, pilot-scale P filter system under real field conditions.

Field site and system design

A pilot-scale filter system was installed near Fensholt, Denmark, treating tile drainage water from a 25 ha loamy arable field.

Water was pumped into the system from a collector drain. Three ISCO samplers enabled continuous water monitoring from October 17, 2020, to May 29, 2021.

Statistical analysis

Statistical analyses were conducted in R (v4.3.3) using generalized additive models (GAMs). Models assessed the performance of the sediment and reactive filters in retaining:

- total P (TP),
- particulate P (PP),
- total dissolved P (TDP).
- suspended sediments (SS).

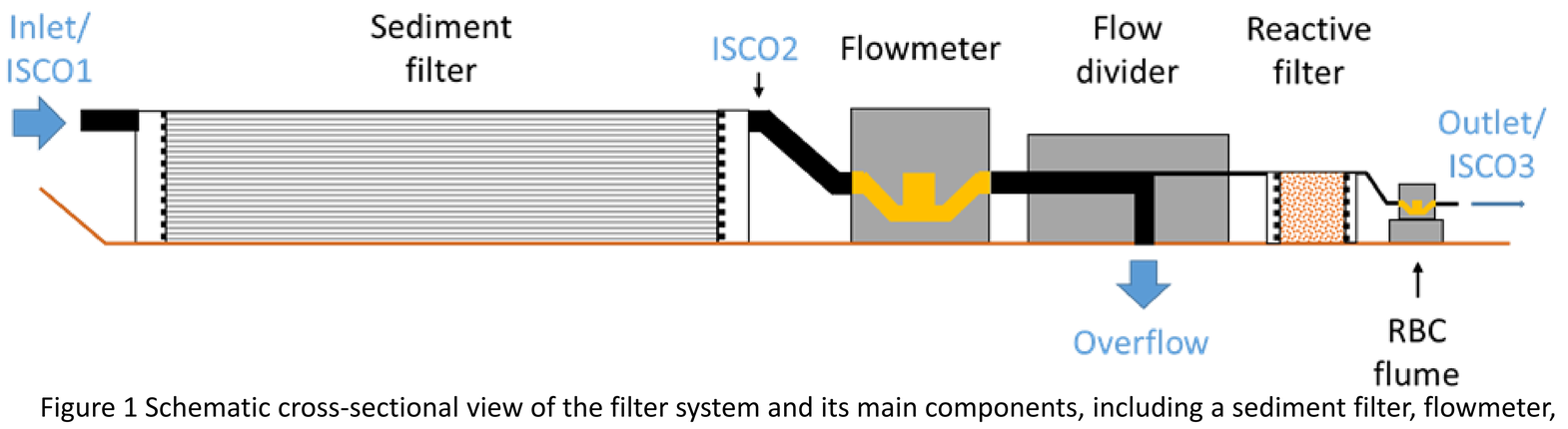

Figure 1 Schematic cross-sectional view of the filter system and its main components, including a sediment filter, flowmeter, flow divider, reactive filter filled with iron coated sand (ICS), an RBC flume and automatic water samplers (ISCO1-3).

Hydraulic Performance and Phosphorus Removal

The sediment filter treated an average flow of 0.8 L/s (28% of drainage discharge), with peak flows of 2.8 L/s and average HRT of 135 min. The reactive filter operated with an average flow of 0.1 L/s (10% of sediment filter flow) and HRT of 25 min. Total P concentrations (61% PP and 39% TDP) at the sediment filter inlet ranged from 0.03–2.47 mg/L (avg. 0.24 mg/L), with higher values early and late in the season. The sediment filter showed strong PP retention (≥56% before March 2021), confirmed by GAM analysis, and was largely unaffected by water characteristics. The reactive filter showed high TDP retention (≥57%), with values declining towards the end of the season due to reduced sorption capacity.

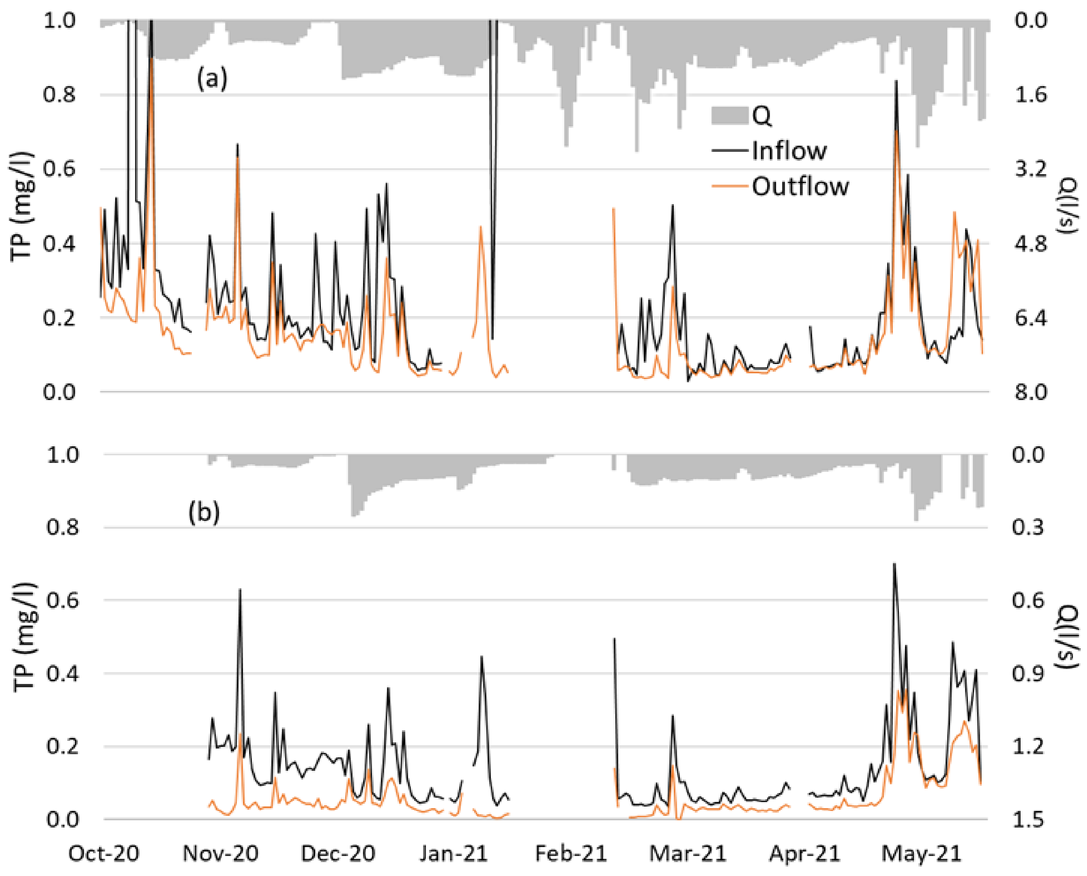

Figure 2 Daily total phosphorus (TP) concentrations (mg/l) for (a) the sediment filter and (b) the reactive filter, at both the inlet and outlet. The hydraulic load (Q) is given on the secondary axis. No water samples were collected between 29th of January and the 23rd of February

Month	n	Sediment filter Q	TDP Load	TDP Removal	PP Load	PP Removal	SS Load	SS Removal	Reactive filter Q	TDP Load	TDP Removal	PP Load	PP Removal
		(m^3)	(g)	(%)	(g)	(%)	(kg)	(%)	(m^3)	(g)	(%)	(g)	(%)
Oct-20	16	397	190	23	53	56	11	73					
Nov-20	27	1153	207	16	69	75	11	79	59	10	79	2	14
Dec-20	31	1798	250	2	197	75	30	76	225	23	61	7	18
Jan-21	21 (25)	1050	74	20	180	75	13	66	175	9	72	8	79
Feb-21	4 (5)	188	17	16	5	67	2	49	12	1	68	2	72
Mar-21	31	3245	228	10	235	69	23	72	272	15	58	3	68
Apr-21	26	1583	108	2	25	60	8	72	158	10	57	1	28
May-21	23	2639	403	-7	178	42	33	63	264	41	29	12	15

Table 1 Monthly hydraulic loading (Q), load and removal of total dissolved phosphorus (TDP), particulate phosphorus (PP) and suspended sediments (SS) for the sediment and reactive filter. Number of days (n) with P measurements is also given, with parenthesis indicating the value for the reactive filter if different from the sediment filter.

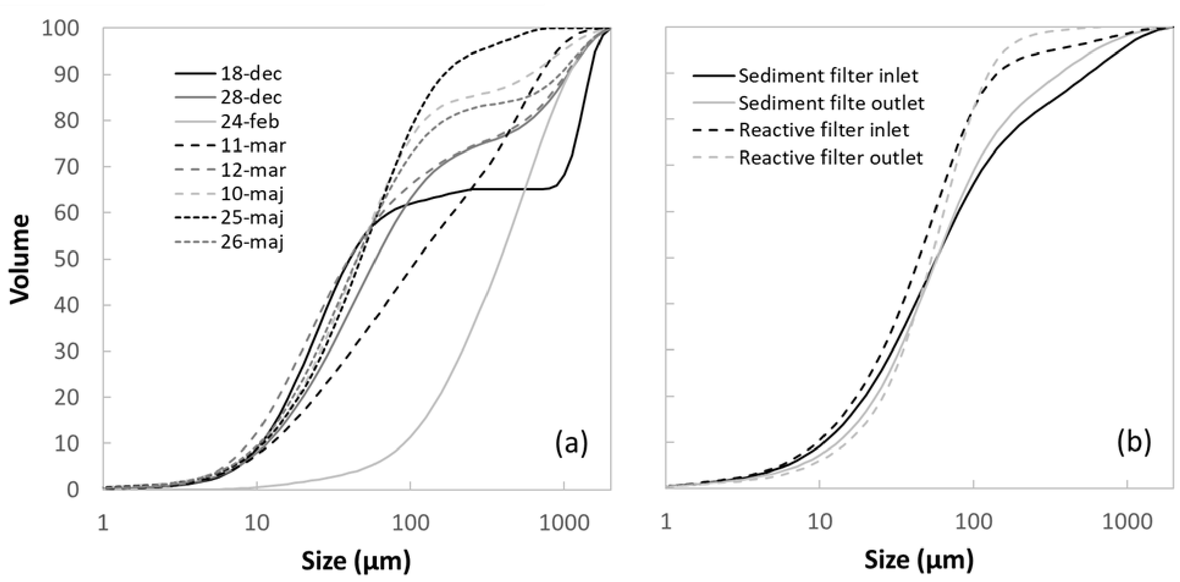

Figure 3: Cumulative undersize distribution (a) in the inlet drainage water during the monitoring period and (b) in the sediment samples, collected from the sediment and reactive filter units.

Sediment filter performance

Suspended sediment loss by macropore transport to drains, closely linked to PP transport, is common in fine-textured soils during peak-flow events. Here, turbidity was used as a proxy for suspended sediments and showed strong temporal variability, with frequent peaks before January and again in May 2021. Turbidity was generally lower at the sediment filter outlet, indicating sediment removal.

Reactive filter performance

Batch experiments showed high sorption capacity in both fresh and used iron coated sand (ICS) material from the top of the filter, suggesting limited saturation in this area due to the upward flow design, which leads to faster P saturation at the bottom. In contrast, used ICS from the bottom had much lower sorption capacity, indicating saturation.

Conclusions

The system treated >12,000 m^3 of drainage during 8 months retaining on average 70% of TP. The sediment filter effectively retained PP (42–75%), especially larger particles (>90 µm), while the reactive filter removed 29–79% of DRP.

Despite strong overall results, the study highlights challenges with sediment filter capacity and potential P remobilization, underscoring the need for further research on sediment dynamics, optimal maintenance, and long-term system performance.