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Phosphorus in soil treatment systems: Accumulation and mobility

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ABSTRACT

Septic tanks with subsequent soil treatment systems (STS) are a common treatment technique for domestic wastewater in rural areas. Phosphorus (P) leakage from such systems may pose a risk to water quality (especially if they are located relatively close to surface waters). In this study, six STS in Sweden (11–28 years old) were examined. Samples taken from the unsaturated subsoil beneath the distribution pipes were investigated by means of batch and column experiments, and accumulated phosphorus were characterized through X-ray absorption near edge structure (XANES) analysis. At all sites the wastewater had clearly influenced the soil. This was observed through decreased pH, increased amounts of oxalate extractable metals and at some sites altered P sorption properties. The amount of accumulated P in the STS were found to be between 0.32 and 0.87 kg m^{-3}, which in most cases was just a fraction of the estimated P load (<30%). Column studies revealed that high P concentrations (up to 6 mg L^{-1}) were leached from the material when deionized water was applied. However, the response to deionized water varied between the sites. As evidenced by XANES analysis, aluminium phosphates or P adsorbed to aluminium (hydr)oxides, as well as organically bound P, were important sinks for P. Generally soils with a high content of oxalate-extractable Al were also less vulnerable to P leakage.

1. Introduction

Phosphorus (P) discharge from anthropogenic sources is a crucial factor for eutrophication of many inland aquatic systems worldwide (Smith, 2003). In most areas, agricultural activities are believed to account for the majority of the P discharge on an annual basis (e. g. Smith et al., 2005; Brandt et al., 2009). The contribution from onsite wastewater treatment systems (OWTs) is smaller but they can still be a relevant P source, especially in areas such as the Baltic sea region

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where the reduction of P loads is of high priority (Boesch et al., 2006; Wulff et al., 2007).

Among OWTs, the use of septic tanks with subsequent soil treatment systems (STS) is the most predominant treatment technique for domestic wastewater. The use of STS is extensive in rural parts of Australia, North America, Canada and parts of Europe (Butler and Payne, 1995; USEPA, 2002; Beal et al., 2005; Weiss et al., 2008; Gill, 2011; Motz et al., 2012). In STS, the unsaturated subsoil beneath the soil trench and above the water table can be defined as the overall treatment system (Gill et al., 2009). In clay soils (which are not suitable for infiltration) the STS can be constructed using imported sand. The wastewater then has to be drained out at the bottom of the system and piped to a surface recipient.

Phosphorus removal in STS is attributed to chemical precipitation and sorption processes in the soil matrix. Formation of Al(III) and Fe(III) (hydr)oxide surface complexes or precipitation of Al(III), Fe(III) and/or Ca phosphates are all possible attenuation mechanisms (Robertson, 2003; Eveborn et al., 2012). In addition Fe(II) precipitates may form at low redox potential (Zanini et al., 1998).

From a recipient perspective it has been shown that OWT systems can be a significant factor for the P status of freshwaters under certain conditions (Macintosh et al., 2011; Withers et al., 2011); these authors suggested that the observed impacts are attributed to poor design or insufficient maintenance of the treatment systems rather than general leakage. However, in the scientific literature there has been observations of both high, variable and low P removal (e.g. Carroll et al., 2006; Lowe and Siegrist, 2008; Robertson, 2008; Eveborn et al., 2012; Robertson, 2012).

As support within management of decentralized wastewater sources, knowledge regarding long term P removal in STS and the P immobilization/mobilization mechanisms involved is important. Eveborn et al. (2012) used a mass balance approach to assess the P removal capacity of the unsaturated subsoil in a Swedish STS. The study gave evidence for a very poor P removal (~12%), but was limited to four sites with comparably high P loads. The aim of this study was to explore the validity of the results by performing additional (simplified) mass balance calculations and investigate both accumulation and mobility of P in the unsaturated subsoil of old STS. Specific aims were to:

1. Investigate the overall removal capacity in the unsaturated subsoil of the systems by calculating the amount of accumulated P.
2. Study the P leaching and P removal potential of soil materials from STS through pilot scale column experiments with reconstructed bed profiles.
3. Investigate the mechanisms behind the observed P retention and P release by evaluation of data from batch experiments and physical/chemical characterization (including X-ray absorption near edge structure (XANES) measurements).

2. Materials and methods

2.1. Investigated sites

Six STS located in various parts of Sweden were investigated: Tullingsås (Tu) near Östersund N 63° 49.17', E 15° 31.09', Biverud/Glanshammar (Gl) near Örebro N 59° 19.95', E 15° 27.90', Knivingaryd (Kn) near Nybro N 56° 54.45', E 15° 57.44', Luvehult (Lu) near Nybro N 56° 52.59', E 16° 6.95', Ringamåla (Ri) near Karlshamn N 56° 21.94', E 14° 44.26' and Halahult (Ha) near Karlshamn N 56° 14.05', E 14° 58.06'. Among these sites Lu and Gl were traditional single-household systems whereas the other ones served between 40 and about 200 persons each (Table 1). The age of the sites varied between 11 and 28 years, the hydraulic load was between 0.9 and 33 cm d^{-1} and the estimated P load was between 30 and 540 g m^{-2} yr^{-1} (Table 1). At the Kn site a lined pond (open to the air) was used as a pre-

Table 1 – Description of studied soil treatment systems.

	Tu	Gl	Lu	Kn	Ri	Ha
Design base (pe)	225	5	5	75	150	100
Connected (pe)	n.a.	6	4	40	n.a.	n.a.
Surface area(s) (m^2)	2 x 196	30	50	80	2 x 160	2 x 50
Hydraulic load[a] (cm d^{-1})	33	2.2	0.9	25	n.a.	30
P load (g m^{-2} yr^{-1})	370[c]	80[b]	30[b]	200[b]	n.a.	540[c]
Age (year)	18	20	23	11	28	24
Pre treatment	Septic tank	Septic tank	Septic tank	Lined pond	Septic tank	Septic tank
Wastewater distribution	Gravity fed, open surface distribution	Gravity fed, drain field	Gravity fed, drain field	Pump fed, drain field	Pump fed, drain field	Pump fed, open surface distribution
Thickness of soil bed (m)	>1	>1	>1	0.9	0.8	0.9
Discharge	Drained to surface water	Ground-water	Ground-water	Ground-water	Drained to surface water	Drained to surface water

[a] Based on annual mean flows and active infiltration areas (where several beds are shifted). Mean flows for the sites Gl, Lu and Kn have been calculated based on a water usage equivalent to 180 L $person^{-1}$ d^{-1} and 60% home attendance. Mean flows at other sites taken from Bylund (2003).

[b] An estimation based on mean flows (as described above), total infiltration area and a 10 mg L^{-1} P concentration in the wastewater (Jönsson et al., 2005).

[c] Calculated from a dataset of ~50 inflow and P concentration measurements (Bylund, 2003) and total infiltration area.