



Loss of soil phosphorus by tile drains during storm events



Dana Zimmer^{a,*}, Petra Kahle^b, Christel Baum^a

^a Soil Science, University of Rostock, Justus-von-Liebig-Weg 6, D-18051 Rostock, Germany

^b Resource Conservation and Soil Physics, University of Rostock, Justus-von-Liebig-Weg 6, D-18051 Rostock, Germany

ARTICLE INFO

Article history:

Received 5 August 2015

Received in revised form 7 December 2015

Accepted 14 December 2015

Available online 13 January 2016

Keywords:

Phosphorus leaching

Ochre flocs

Element mapping

Protection of surface water

Water quality

ABSTRACT

Phosphorus losses from agricultural soils are usually predominately caused by surface-runoff and only rarely by tile drain discharge. However, storm events can drastically increase P transfer to water bodies. In 2011 summer storm events caused 3.2 fold higher precipitation compared to the long-term average in Northern Germany. During these storm events excessive yellow-brown ochre flocs were observed in drain discharges and supposed to be potential P carrier. Therefore, water samples with ochre flocs were taken and analyzed by light and electron microscopy and for total elemental concentrations of P and its common binding partners (Al, Fe, Mn). Additionally, sandy sediment samples were taken in winter and analyzed for total and oxalate-extractable amounts of these elements. Water samples with ochre flocs revealed total P concentrations of approximately 27 to 141 mg l⁻¹. During the high discharge period a cumulative discharge of 124.6 mm from a drain plot of 4.2 ha was recorded, which resulted in a calculated minimum loss of 34 kg P_t ha⁻¹. This was assumed to be promoted by the excessive occurrence of ochre flocs, which were mainly formed by fungal mycelia with precipitated Fe- and Mn-(hydr)oxides at the surface. The poor crystallinity of the Fe-oxides from the discharge of tile drains was confirmed by an amount of up to 94% of active Fe-oxides in the sandy sediment. The extremely high discharge from tile drains, the flocky nature of the ochre along with a poor crystallinity of Fe-oxides and high P concentrations possess the risk of increased input and bioavailability of P in water bodies. Therefore, discharge and P forms from tile drained areas should be monitored more intensively and retention of P on tile drain outlets should be considered to prevent water bodies from eutrophication.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Phosphorus (P), a major plant nutrient, is frequently responsible for the eutrophication and ecological damage of rivers, lakes and seas such as the Baltic Sea (Daniel et al., 1998). In Germany the P input through waste water from households and industry into water bodies decreased by more than 71% from 1985 to 2005 due to improved waste water treatment (UBA, 2010). However, worldwide agricultural sites are a lasting major source of P input into water bodies (Gentry et al., 2007; McDowell and Trudgill, 2000; Smith et al., 2001). Leaching losses from agricultural soils can be a potential P source, especially since tile drainage is a common practice in agriculture to decrease soil moisture and improve aeration conditions especially in lowland catchments. Drainage shortens the residence time of water in the soil and therefore forms an important pathway for solutes—especially nitrate—to surface water bodies (Kladivko et al., 1999). The effect of tile drainage on the loss of P

is controversially discussed (Sims et al., 1998; Skaggs et al., 1994). Baker et al. (1975) estimated that only low amounts of P were lost by drainage systems compared to that of surface runoff. Controversially, McDowell and Trudgill (2000) pointed to the relevance of the P-status of the soil for the emission of P. Similarly, Madison et al. (2014) highlighted that the subsurface pathways contributed to 17–41% of the total P loss from sites with heavily manured soils. Tiemeyer et al. (2009) determined low P concentrations in tile drainage water in German lowland catchments, but highlighted the relevance of preferential flow paths along earthworm burrows and root channels. Stamm et al. (1998), Laubel et al. (1999) and Norgaard et al. (2012) found preferential transport of P to be an important pathway to tile drains too. Due to this importance for P transport Ulén et al. (2011) concluded that artificial drainage systems should be included in P risk assessment.

In Mecklenburg-Western Pomerania (North-Eastern Germany) the tile drained area is estimated to 885,000 ha, 53% of the arable land and 83% of the grassland (Koch et al., 2010). The discharge of drain water mainly occurs in winter (from December to March), while in summer (from May to October) only low rates contribute to the annual discharge (Tiemeyer et al., 2009). Usually tile drains

* Corresponding author. Fax: +49 381 498 3122.

E-mail address: dana.zimmer@uni-rostock.de (D. Zimmer).

fall dry in summer due to high temperature, evapotranspiration and water levels below tile drains and are therefore no critical pathway of P transfer. However, storm events and following discharge can strongly affect the P transfer (McDowell et al., 2001; Schelde et al., 2006). P transfer is based on mobilization from main binding sites which were described to be iron (Fe) and manganese (Mn)-(hydr) oxides (Gerke, 1993; Liu and Hesterberg, 2011). The compounds of Al, Fe and/or Mn can be precipitated and form the so called ochre, which is the most serious and widespread deposit in drainage systems (Ford, 1979; Houot and Berthelin, 1992).

In summer 2011 storm events in Northern Germany caused an about 3.2 fold higher rain fall from June to August compared to the longtime average (Miegel et al., 2014). During and after these storm events excessive yellow-brown ochre flocs were observed in the drain discharge for some weeks.

We hypothesized, (I) that in these ochre flocs P is accumulated and bound in considerable amounts preferentially to Fe and Mn and (II) these will cause high P loads to surface water bodies and their sediments. In order to test these hypotheses, water samples with ochre flocs were taken and analyzed by light and electron microscopy and for their total content of Al, Fe, Mn and P. Additionally, sandy sediment samples were taken in winter and analyzed for the total and oxalate-extractable amounts of Al, Fe, Mn and P. The objectives of this study were (1) to explain the structure and composition of the ochre flocs and the composition of the sandy sediment and (2) to evaluate the P release from drains and the role of storm events for the quality of surface water bodies.

2. Material and methods

2.1. Study area

The study area Dummerstorf is located about 15 km southeast of the city of Rostock (latitude 54°00'10.76", longitude 12°15'07.93" [WGS84], Mecklenburg-Western Pomerania, Northern Germany) in a pleistocene lowland landscape. Long-term mean annual precipitation is 689 mm, reference crop evapotranspiration is 490 mm and temperature is 8.3 °C.

In November 2003 a measurement program was initiated at a collector drain outlet of a tile drainage plot of 4.2 ha (drainage depth 1.1 m, drainage space 8–22 m). The study site is located in the small (15.5 km²) rural catchment of the brook Zarnow, a tributary of the river Warnow, which is discharging into the Baltic Sea. The sampling station consists of a climate station, a Venturiflume (Eijkelpark Agrisearch Equipment, Giesbeek, The Netherlands) for discharge measurement and an automatic sampler (Teledyne Isco, Inc., Lincoln, NE). The land use in the catchment is dominated by agriculture (48% arable land, 28% grassland and 14% forests). Typically for the area, the soil is a Gleyic Luvisol (FAO, 1998) derived from glacial deposits. The soil texture was mainly identified as sandy loam and loamy sands. The topsoil (0–30 cm) has about 2% organic matter, 75 mg kg⁻¹ plant available P, 100 mg kg⁻¹ plant available potassium (K) and a pH-value of 6.4 (Kahle and Lennartz, 2005). Based on the German nutrient classes “very low”, “low”, “optimal”, “high” and “very high”, the plant nutrient supply was “optimal”, i.e. 56–80 mg kg⁻¹ plant available P determined by double lactate extraction (Vdlufa, 1997). In the topsoil the total concentration of P was 424 mg kg⁻¹, of K 1418 mg kg⁻¹, of Ca 1633 mg kg⁻¹, of Fe 13 g kg⁻¹ and of Al 8.4 g kg⁻¹ (Kahle et al., 2013). Oxalate extracts of the soil were made to evaluate the percentage of active Fe oxides (Fe_{ox}), the P sorption capacity (PSC in mmol kg⁻¹) and the degree of P saturation (DPS in%) of these oxides in the topsoil (Leinweber et al., 1997). The percentage of active Fe oxides (Fe_{ox}/Fe_T) was 19%. According to the oxalate extract the PSC of the soil was 334 mmol kg⁻¹ and the DPS was 33%.

The crop rotation of the tile drained plot was winter wheat (*Triticum aestivum* L.) in 2009, corn (*Zea mays* L.) in 2010, and winter barley (*Hordeum vulgare*) in 2011. P was applied as mineral and organic fertilizers. The P fertilization ranged from 10 to 67 kg ha⁻¹ year⁻¹ (2009–2011). The calculated P output by crop uptake is equal to P input by the fertilizers.

The dynamics and the extent of total P (P_T) and total reactive P (TRP) concentrations as well as the discharge were monitored at the drain outlet for the winter seasons 2003/04, 2004/05 and 2005/06. The P_T concentrations (90. Percentile) in the discharge of the collector drain varied from 0.057 to 0.158 mg l⁻¹ P_T as well as 0.026 to 0.124 mg l⁻¹ TRP allowed the water quality to be classified as ‘moderately polluted’ (water quality class II according to LAWA, 1998). Drain discharges from a minimum of 87 mm to a maximum of 190 mm resulted in a maximum P loss of 120 g P_T ha⁻¹ per winter season. The study has also shown the event-based behavior of the P losses and the occurrence of higher P concentrations due to preferential flow (Tiemeyer et al., 2009). The drain water has a pH value of around 7.

2.2. Sampling after storm events and sampling in winter

With ochre flocs enriched water was recognized in the Venturiflume after the storm events in July 2011. Samples were taken at different positions of one venture flume (Table 1). Sample 1 was taken on 25-August-2011 from the flowing water (with floating ochre flocs) in the Venturiflume near the drain outlet. On 01-September-2011 two samples from the flowing water (with floating ochre flocs) were taken, one directly from the drain outlet (sample 2) and the other from the end of the venture flume (sample 3).

All water samples were taken in 100 ml PE bottles and stored in a fridge (10 °C) for a maximum of 3 weeks till the chemical analyses. During this time span subsamples were analyzed by light microscopy, prepared for electron microscopy and prepared for the identification of flocbuilding microorganisms. The samples were not acidified in order to preserve the initial biogenic structure of the ochre floc matrix until analyses.

Samples 4–6 were taken at the beginning of the flume directly under the drain outlet in December 2011 and January 2012 when “normal”, sandy sediment was recognized at drain discharge (Table 1). These sediment samples were also taken in 100 ml bottles within flowing water and also not acidified, to preserve changes in the status of Fe-oxides and sorbed P. In contrast to these sandy sediments, which settled fast in the bottles, only very small amounts of the ochre flocs settled even after days. The originally yellow-brown colored ochre flocs developed a darker brown color within some days in the fridge. The rusty color of the sediment did not change visibly.

2.3. Light and electron microscopy

Some drops of each sample 1–3 (OFS 1 to OFS 3) were mixed into fluid 2% water agar (Roth) to preserve the three-dimensional structure of microbial flocs (Droppo et al., 1996). The hardened samples were stored in the fridge for some days. Some of the ochre flocs (with agar) were cut out for preparation for electron microscopy images. These samples were dehydrated by stepwise increasing ethanol concentrations (30, 50, 70, 90 and 2-times 100%) with an exposure time of 10 min for each step. The dehydrated samples were dried by a critical-point-dryer by liquid carbon dioxide. At least the samples were fixed by hot glue at the sample holder and sputtered with carbon.

Images of the samples were taken by a scanning electron microscope (DSM 960 A, Carl Zeiss, Oberkochen, Germany). Additionally, the samples were analyzed for general elemental composition and

Download English Version:

<https://daneshyari.com/en/article/4478321>

Download Persian Version:

<https://daneshyari.com/article/4478321>

[Daneshyari.com](https://daneshyari.com)