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Losses of sediment and phosphorus through subsurface drains in a clayey field in southern Finland

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Abstract

Seasonal and short-term transport of eroded soil (TSS), total phosphorus (total P) and dissolved orthophosphate phosphorus (DP) via tile drains were studied using on-farm monitoring data from a clayey field under cereal cultivation. The subsurface drainage system was installed in 1951. The proportions of drain flow and surface runoff varied both on seasonal and event basis. On an average, subsurface drain flow constituted about 50% of the annual total runoff during the study years, 1995, 1996 and 1998. The range of the TSS and total P concentrations in drain flow was similar to the concentrations in surface runoff. The peak concentrations with both flow components occurred in autumn after soil tillage. Clearly lower concentrations were observed in winter and spring in spite of high runoff volumes. Major part of total P was transported as adsorbed on soil particles. In 1998 with high precipitation throughout the year, transport with drain flow accounted for 32% of the annual TSS losses, 28% of the total P losses and 42% of the DP losses. Transport via preferential flow seemed to be the main pathway from the topsoil to the drains. The results point out need of measures to reduce TSS and PP losses via drain flow and to improve environmental profits of subsurface drainage in clayey soils.

1. Introduction

Phosphorus (P) losses from arable soils account for about 60% of the total human induced P load entering watercourses in Finland. Phosphorus bound on soil particles forms major part of the total agricultural P load (Vuorenmaa *et al*. 2002). Subsurface drainage generally has a beneficial influence on surface water quality, because drainage reduces surface runoff, erosion and P load. However, high sediment and P losses have been observed to occur through pipe drainage systems in experimental sites in Finland (Seuna & Kauppi 1981; Turtola & Jaakkola 1995; Uusitalo *et al*. 2001) and in other Nordic countries (Djodjic *et al*. 2000; Grant *et al*. 1996; Ulén 1995, Ulén & Persson 1999, Ulén & Mattsson 2003; Øygarden *et al*. 1997). Tile drains might be an important pathway of P losses in southern and south-western Finland where major part of arable land is subdrained clayey fields.

The aim of this study was to quantify losses of suspended solids (TSS), total P, and dissolved reactive P, and to improve understanding of how TSS and P are transported through the tile drains on the field-scale. Subsurface drain flow regime and variation of TSS and P concentrations during single rainfall-runoff events and different seasons were investigated using on-farm monitoring data.

2. Materials and methods

The data used in the analysis covers the years 1995, 1996 and 1998 from the Sjökulla experimental site located in southern Finland (60º15' N, 24º27' E). Soil within the field is classified (Soil Survey Staff 1998) as a very fine Aeric Cryaquept (Peltovuori et al. 2002) and the clay content of the soil varies from 38 to 90% increasing with the depth. The slope of the field is 2–4.7%. The field was subsurface drained in 1951, when clay tile drains were installed at depths varying from 0.7 m to 1.5 m. The distance between the drains is about 13 m. Small grain crops were grown in the field with annual P fertilizer amount of 9–20 kg ha^{-1}. Ploughing or stubble cultivation was used in autumn and seedbed preparation in spring.

Outflow from a subsurface drained field section was determined by measuring water level at an observation well with a v-notched weir and a pressure transducer. The area of the field draining through the weir was 3.14 ha. Surface runoff from a smaller field section (0.63 ha) was measured with another v-notched weir. A weather station recorded basic meteorological variables at the site. Hourly values of air temperature, precipitation, subsurface drain flow, and surface runoff were calculated from measurements recorded every 15–30 minutes.

An automatic sampler with a sampling interval of 4 hours was used to study quality of subsurface drainage water during non-freezing period in 1995 and 1998. During early spring and late autumn in 1995 and 1998, and in the year 1996 drainage water samples at the weir outlet were collected manually at irregular intervals. Surface water samples during the study periods were collected only manually.

Total suspended solids (TSS) in water samples were evaluated in 1995 and 1996 by measuring the mass of dried (105 °C) matter retained on the 1 μm fibreglass filter. In 1998, the TSS concentration was determined by weighing the evaporation residue. Total phosphorus (total P) was determined in 1998 using autoclave-mediated digestion with $K_2S_2O_8$ and H_2SO_4 of an unfiltered subsample. Dissolved orthophosphate phosphorus (DP) was determined in April-December 1995, and in 1996 and 1998 by using the FIA autoanalyser and the method of Tecator Application Note (ASN 60–05/90). For the DP analysis the sample water was filtrated through a 0.4-μm Nuclepore filter.

3. Results and Discussion

Subsurface drain flow constituted about 50% of the annual total runoff (drain flow + surface runoff) during the study years. Largest runoff volumes were measured in spring and autumn times. The proportions of drain flow and surface runoff varied both on seasonal and event basis. Surface runoff generally dominated the runoff response to snowmelt and rainfall events in January-April. Almost all runoff in May-August discharged through the tile drains and small volumes of surface runoff were measured only occasionally. High monthly volumes of subsurface drain flow were observed in November 1996 (71 mm) and in October 1998 (25 mm) when the amount of rainfall was exceptionally high. The proportions of drain flow in these two months were 56% and 31% of the total runoff, respectively. Antecedent soil moisture conditions in the late summer and early autumn partly explain the difference in the generation of subsurface drain flow in these periods. In autumn 1995, when precipitation was lower than in 1996 and 1998 and the soil was covered by autumn rye, almost all runoff discharged via subsurface drains.

The range of the measured TSS concentrations was 0.006–6 g l^{-1} in subsurface drainage water and 0.016–7 g l^{-1} in surface runoff samples. The concentration of total P in 1998 varied from 0.04 to 6.6 mg l^{-1} in subsurface drainage water and from 0.14 to 6.7 mg l^{-1} in surface runoff. The maximum TSS and total P concentrations for both subsurface drain flow and surface runoff were measured in late autumn during high flow events. On an average, clearly lower concentrations were observed in early spring in spite of high runoff volumes. The maximum DP concentration was 0.24 mg l^{-1} in subsurface drainage water and 0.41 mg l^{-1} in surface runoff. The highest values were observed in spring 1996 when the soil was covered with autumn rye.

Available hourly data reflected the rapid nature of drain flow generation, and TSS and P transport. Figs. 1 and 2 illustrate how TSS, total P and DP concentrations in subsurface drain flow change during summer and autumn 1998. Increase of TSS and total P concentrations was clearly seen after autumn tillage. A similar behaviour was observed in November 1996. In autumn 1995, TSS concentrations in subsurface drain flow remained much lower (maximum value 1.5 g l^{-1}) than in autumn 1996 and 1998. This was most likely explained by the presence of the crop cover (autumn rye) that improved soil stability and reduced generation of surface runoff. The dependency between TSS and total P concentrations was also visible during other seasons because major part of transported total P was adsorbed on soil particles.

Heavy rains and runoff in autumn after soil tillage induced most of erosion and total P losses in the study years. In 1998, the annual loss of eroded soil estimated from flow and concentration measurements was 1508 kg ha^{-1} via tile drains. About 50% of this load was generated in October and 21% in August. The TSS load via drainage system accounted for 32% of the annual loss. In 1998, subsurface drain flow accounted for 28% of the annual total P loss and 42% of the annual DP loss.

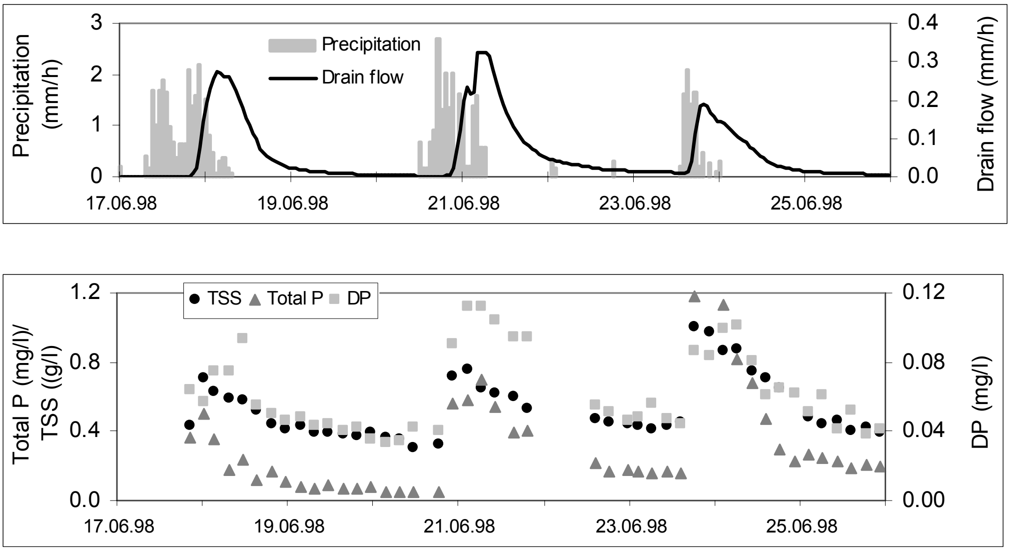

Figure 1. Hourly rainfall and subsurface drain flow (a), and TSS, total P, and DP concentrations (b) in drainage water on 17–25 June 1998. The total amount of rainfall was 53 mm, subsurface drain flow 12.2 mm and surface runoff 0.3 mm. Fertilizer (9 kg P ha^{-1}) was applied on 17 May.

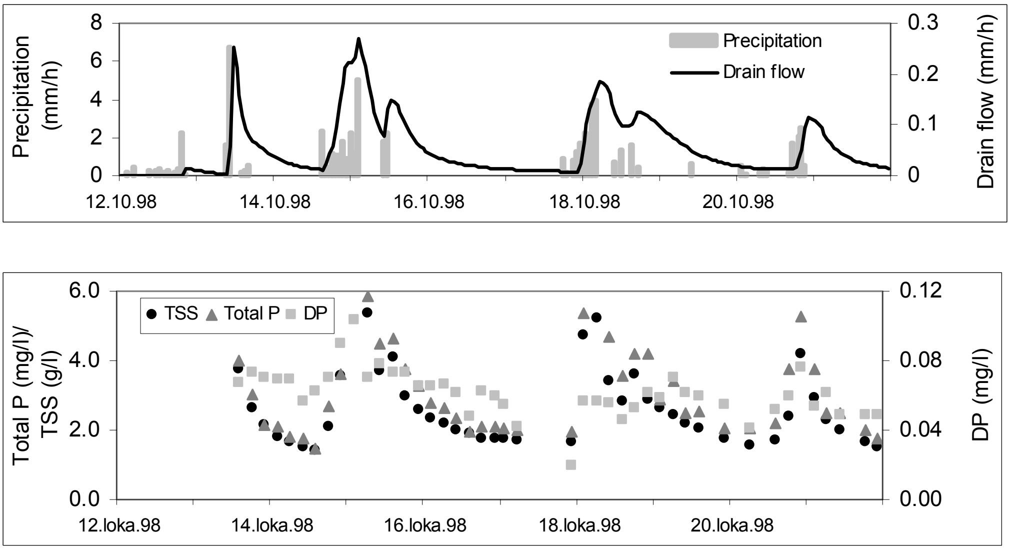

Figure 2. Hourly rainfall and subsurface drainage flow (a), and TSS, total P, and DP concentrations (b) in drainage water on 12–21 October 1998. The total amount of rainfall was 68 mm, subsurface drain flow 12.6 mm and surface runoff 33 mm. The field was partly ploughed and partly cultivated on 2–7 October.

The estimated annual TSS losses at the Sjökulla site were in line with the range measured in the other Finnish experimental fields in clayey soils (e.g. Puustinen 2005). The total P and DP losses were clearly higher in Sjökulla than in the other experimental fields or agricultural catchments (Puustinen *et al*. 2005, Turtola & Jaakkola 1995, Vuorenmaa *et al*. 2002). One reason for this difference is that the Sjökulla data represented only one year (1998) with high depths of autumn rainfall. Another reason might be the irregularity of water sampling. However in Sjökulla, the load estimates via drain lines in May-October 1998 were mainly based on point samples taken with 4-hour interval. The periods with this short-term sampling accounted for 82% of the annual total P and 71% of the annual DP loss. More uncertainty was involved in load estimates via surface runoff which was solely based on manual samples.

The drain flow response to rainfall was very rapid indicating occurrence of preferential flow through the soil. According to ^{137}Cs measurements conducted in Sjökulla, the soil particles in the drainage water mainly originated from the topsoil, which also indicated presence of preferential flowpaths (Uusitalo *et al*. 2001). It is assumed that at the Sjökulla site the transport of water, TSS, and P into drains mainly occurs through natural macropores (cracks, fissures, root channels and earthworm burrows). In addition to macroporosity, the drainage system itself (drain envelop, back-filled trench) might have an impact on the transport mechanisms. Alakukku *et al*. (2006) reported that there is spatial variability in the macroporosity and saturated hydraulic conductivity within the field. The field investigation indicated a higher earthworm density above the tile drains than between them.

4. Conclusions

The on-farm monitoring data collected in this study indicate that, besides surface runoff, drain flow might be an important pathway in transport of suspended solids and phosphorus in subsurface drained clayey fields. Subsurface drainage generally reduces total erosion and P transport from a field, but reduction may be smaller than expected in clayey fields, where preferential flow occurs via backfilled drain trenches and natural macropores. Stabilization of surface soil e.g. by reduced tillage or non-tillage methods, or by introduction of winter cover crops is needed to reduce TSS and particulate P losses with drain flow. Emphasis should also be paid on new drainage techniques and materials that could reduce the losses. Further research is needed to examine soil and total P losses via the tile drains in drainage systems having different age and type and in fields composed of different types of clayey soil.

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