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Nutrient Exports from Two Agriculture-Dominated Watersheds in Southern Sweden

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Nutrient concentrations and exports were monitored for eight years in two agriculture-dominated watersheds in the central part of the Västgöta Plain in Sweden. The hydrology and the nutrient concentrations in the streams were very similar. Concentrations (monthly flow-weighted) of dissolved phosphate-phosphorus (PO_4P) varied substantially during the year (from 0.03 to 0.27 mg l^{-1}) whereas concentrations of particulate phosphorus (PartP) varied less (from 0.03 to 0.16 mg l^{-1}). No trends in nutrient export during the eight years were found after flow-normalization of export data. Three wet periods dominated the long-term loads of the streams. Although a few events dominated annual yields of suspended solids (SS) from drainage pipes, standard deviation of annual mean SS concentration was reasonably constant between different years. However, when further developing phosphorus load models the variation in SS concentration should probably be considered. In-stream processes may contribute nearly as much to the phosphorus export as those occurring on and in arable soils in terms of their impact on the magnitude of phosphorus export. Total nitrogen (TotN) mean concentration was 5 mg l^{-1} and was similar in drainage pipes and in the streams.

Introduction

In the Nordic countries, phosphorus (P) losses from agricultural land is thought to be the main sourse of P into inland waters and the sea (Rekolainen *et al.* 1997). Together with nitrogen (N) P contributes to the eutrophication of inland waters (Schindler 1977), and P loading is perhaps the best measure of the nutrient status of a water

(Dillon *et al.* 1975). P transport and to a lesser extent N transport from drainage pipes may occur very episodically (Grant *et al.* 1996; Skaggs *et al.* 1994; Ulén 1975). Even in small watersheds the nutrient transport may occur in separate episodes in addition to the seasonal and diurnal variations; events that are sometimes called transient pollution events (Beck 1996; Schreiber *et al.* 1996). These events, which can be natural or man-made, tend to be particularly pronounced in small agricultural watersheds. Data regarding nutrient export from such catchments is limited. Studies of small watersheds may indicate whether improved agricultural practices have reduced the export of P and N. The Swedish parliament has stipulated a 50% reduction of N losses and a "subtantial reduction" of P losses from arable land by 1995, with 1987 as the reference year. With this in mind it is of special interest whether any early trend in nutrient export from agriculturral areas can be noted. However, since the flow regimes vary from year to year, long-term data are needed to describe the dynamics of nutrient exports. Also, considering that specific hydrological events can have a strong impact on losses from soil to the water, this may strongly overshadow any positive trends in nutrient loads.

The aim of this paper is to discuss nutrients, especially phosphorus export data in connection with forces driving P and N exports from two typical agriculture-dominated catchments in the southern Sweden.

Materials and Methods

Study Site Description

Streamflow and nutrient concentrations were measured in two small watersheds, Uvered and Tubbetorp which discharge into tributaries of the River Lidan (Fig. 1). They are situated on the Västgöta Plain, the largest agricultural plain in Sweden, have a flat topography and, based on visual inspections there is generally very little overland flow. Both watersheds are dominated by agricultural land which is almost completely drained (Table 1). The drainage pipes empty either directly into the stream, or into the stream ravine, some metres from the water. The Tubbetorp watershed includes parts of the village of Vara but none of the sewage produced by the village ends up in the Tubbetorp watershed. Both watersheds have clay soil. Both the ammonium lactate extracted phosphorus (P-AL) content, measured according to Egnér *et al.* (1960), and the total P content of the Uvered surface soil, measured according to Swedish standard (1990) are typical for Swedish conditions (Table 2). Agriculture in the region is dominated by cereal production, with limited animal husbandry. In 1994 animal units were very low in the Uvered catchment (Table 3). Sewage from 65 persons in 26 households is exported to the stream via single outlets, mostly with a low standard of cleaning. In the Tubbetorp catchment no inventories of cattle or single outlets have been made, but estimates indicate that the number is similar to that in the Uvered catchment. Data of nutrient losses in subsurface

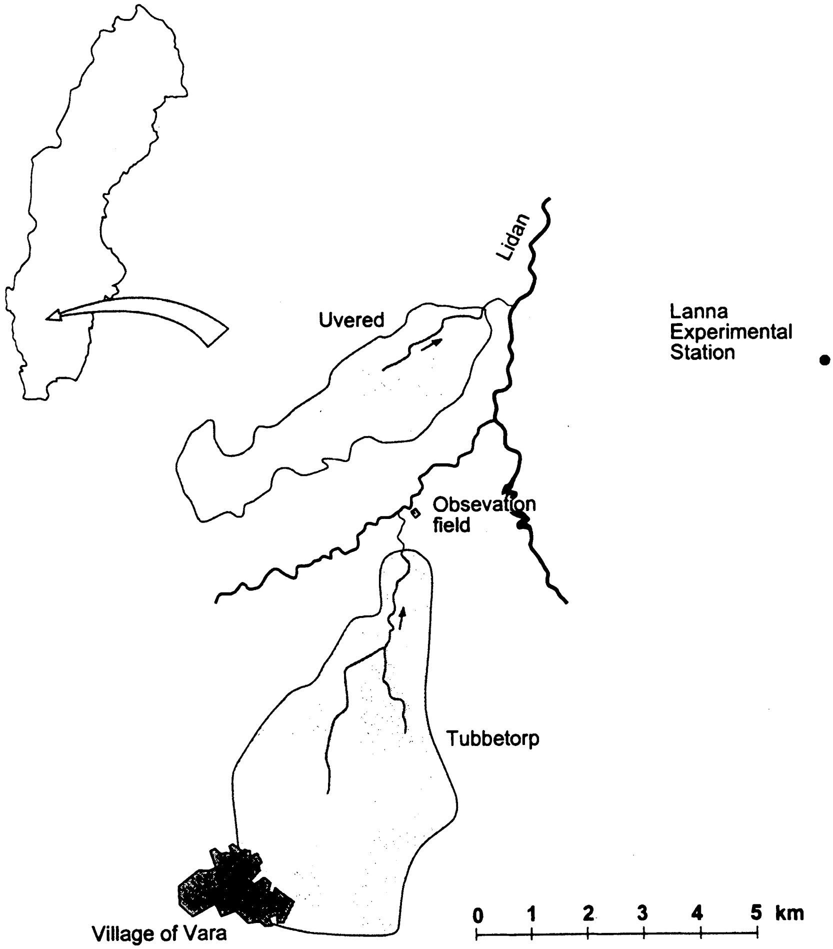

Fig. 1. Location of Uvered and Tubbetorp catchments in southern Sweden.

Table 1 – Characteristics of the studied watersheds. Hydrological characteristics for years 1993-1996, when runoff was measured at all sites.

	Area (ha)	Agricultural area (%)	Urban and road area (%)	Mean slope (%)	Max flow ($l\ s^{-1}\ km^{-2}$)	Mean flow ($l\ s^{-1}\ km^{-2}$)	Number of days without flow (%)
Uvered	813	91	0.2	0.06	146	10.2	10.6
Tubbetorp	1600	91	7.4	0.08	142	10.7	0.4
Lanna	0.4	100	0	0.14	367	7.8	41.7
Obs. field	10.9	100	0	0.4	198	3.8	56.1

Table 2 – Texture, pH and P status (based on dry weight) of surface soil (0-30 cm) in the Uvered watershed and Lanna experimental plot and in the observation field.

	Texture (%)				pH	P-AL	TotP
	Clay	Silt	Fine sand	Coarse sand		(g kg^{-1})	(g kg^{-1})
Uvered	42	29	25	4	6.9	5.6	72
Lanna	49	28	18	5	7.1	5.0	70
Obs.field	47	27	20	6	6.6	5.2	62

Table 3 – Crop rotation, fertilization and number of animal units and persons per hectare.

	Crop rotations	Fertilization		Animal unit*	Persons
		P (kg ha^{-1})	N (kg ha^{-1})	(ha^{-1})	(ha^{-1})
Uvered	Mainly cereals	8	130	0.05	0.08
Lanna	Spring cereals	8	114	0	0
Obs. field	Mainly cereals	10	111	0	0

* one unit is equal to 1 diary cow, 1 horse, 2 heifers, 3 productive sows and 100 laying hens

drains from an experimental plot were collected from Lanna Experimental Station, situated within 10 km from the watersheds. The data were obtained from one of seven experimental plots, which had been subjected to normal agricultural practices. Subsurface drainage water data from an observation field situated close to the Tubbetorp discharge measuring station were also used (Kyllmar *et al.* 1995).

Climatic and Hydrological Data, Water Sampling and Chemical Analysis

Climatic data were collected from Lanna Experimental Station. Flow-proportional sampling of the drainage water had been carried out since 1992 (Ulén 1995). The water samples representing 2.5 mm discharge were added to samples consisting of ten subsamples. Streamflow was measured at Uvered with an open V-notch weir, built in 1993, equipped with a mechanical water level recorder. In the stream at Tubbetorp, a natural section of bedrock and a mechanical water level recorder were used during the entire monitoring period. Discharge was calculated using a rating curve that was checked against several discharge measurements annually.

Water samples were taken manually from the streams every week. They were immediately sent to the Division of Water Management laboratory in Uppsala for analysis. Suspended solids (SS), total phosphorus (TotP), total nitrogen (TotN) and nitrate nitrogen (NO_3N) were determined from the unfiltered water sample. Analyses were carried out in accordance with Swedish Standard (1990). The water was passed through membrane filters (Schleicher & Schnell). Instead of the Swedish standard pore size of 0.45μm a 0.2μm pore size was used in order to retain the finest clay particles. Total phosphorus was also analysed from the filtered sample, as well as phosphate phosphorus (PO_4P). The amount of particle-bound phosphorus (PartP) was calculated as the difference between total phosphorus in unfiltered and filtered water samples. Total phosphorus not covered by PartP or PO_4P is referred to here as dissolved non-reactive phosphorus (DNrP). This fraction may contain dissolved organic phosphorus or inorganic particulate phosphorus in such a fine collodial form that it passes through the filter.

Daily nutrient concentration from stream water, from which water samples were taken momentary, was calculated through linear interpolation. Then calculated daily exports were summed from this to estimate the annual export during an agrohydrological year (1/7-30/6). When comparing concentrations, flow-weighted concentrations were used, *i.e.* transport was divided by runoff for the same period to estimate the mean concentration during the period of measurement. When investigating change over time, a two-step procedure was used as described by Stålnacke and Grimvall (1996). Monthly load data were flow-normalized using a roughness-penalty approach before the trend analyses which were carried out with a non-parametric test using the statistical software Minitab (Visual Basic module).

Results and Discussion

Climate and Hydrology

For most of the years there was no marked winter season with long-lasting snow cover and frozen soil, but temperatures often fluctuated around 0°C, and periods of snow accumulation followed by melting usually occurred several times during the winter. The hydrological responses to the precipitation were similar for the two watersheds. The daily discharge responses resembled each other, with a regression coefficient of 0.84. Due to its smaller size the Uvered basin had more days without any flow (Table 1). The water yield, expressed as the ratio between runoff and precipitation, was 0.52 and 0.54 respectively. In the experimental plot the water yield ratio was 0.39. Mean flow from the observation field was low, probably since it is situated along the stream bank and much of the water probably bypasses the drainage pipes and flows directly into the stream.

Nutrient Concentrations

Nutrient concentrations were similar in the two streams, except for slightly higher concentrations of PartP in the smaller Uvered watershed during summer. Discharge was generally low during July-September. PO_4P concentrations increased markedly during these low-flow summer periods (Fig. 2). Although much of the P was in particulate form, the soluble component represented the main part of the TotP export

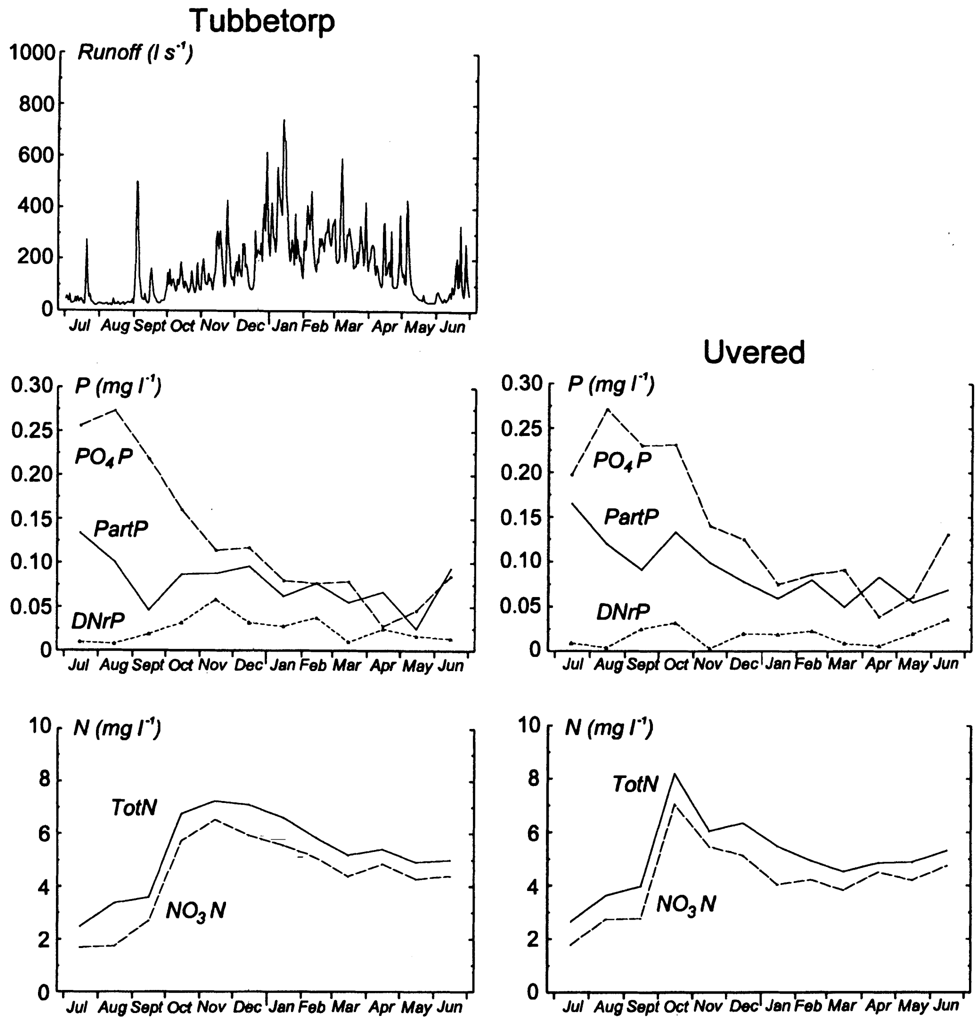

Fig. 2. Seasonal variation of runoff, particulate phosphorus (PartP), phosphate phosphorus (PO_4-P) and dissolved non-reactive phosphorus (DNrP), total nitrogen (TotN) and nitrate nitrogen (NO_3-N) as a mean for 1988-1996.

during the year. PartP showed less temporal variation throughout the season compared with PO_4P. The concentration of DNrP was low.

Both field drainage systems, the experimental plot and the observation field, represent areas of arable farming but are compared with results from the two catchments in this study. This has been done since increased P exports as a result of livestock farming (for instance Grant *et al.* 1996; Hergert *et al.* 1981) have only been reported from areas with much higher stocking densities than those at Uvered and Tubbetorp.

Table 4 – Mean flow-weighted concentrations of nutrients and suspended solids (mg l^{-1}) in Uvered and Tubbetorp during 1988-1996.

	TotP	PartP	PO_4-P	DNrP	TotN	NO_3N	NH_4N
Uvered	0.195	0.068	0.108	0.019	5.21	4.43	0.09
Tubbetorp	0.178	0.053	0.108	0.017	5.26	4.34	0.12
Lanna	0.048	0.020	0.018	0.018	4.60	4.22	-
Observation field	0.056	-	0.025	-	5.98	5.23	-
Single household[a]	0.02	-	-	-	0.12	-	-
Cattle manure[b]	0.02	-	-	-	0.07	-	-

[a] Maximum contribution

[b] Assumed that 5% of the nutrient contents end up in the stream

Assuming that the contributions of N and P from untreated household sewage equal the amounts determined by the Swedish Environmental Protection Agency (1995) and represent maximum loading, so that no reduction of nutrients takes place in the single household outlets, household sewage would increase P concentration by 0.02 mg l^{-1} a^{-1} (Table 4). N and P amounts in cattle manure were calculated from standard values determined by Claesson and Steineck (1991). Loading of 5% of TotP from this manure into the stream would contribute an additional amount of P equal to the P discharge from household sewage. Although this may be regarded as the maximum contribution from point sources, the difference between P concentrations in the streams and those in the drainage pipes was still very pronounced (Table 4). Either spatial heterogeneity in drainage concentrations was so high that concentrations from both Lanna Experimental Station and the observation field were not representative for the two catchments, or there were other processes important in determining P export once the drainage water had left the pipes. These other processes would be of similar importance as the contribution from drainage pipes. Since a discrepancy between P concentrations in the streams and those in the drainage pipes was also observed in other clay dominated areas (Ulén 1992), the latter possibility should be given serious consideration.

Nitrate concentrations increased during late autumn and winter (Fig. 2). Nitrogen concentrations in water from the two drainage pipes and from the two catchments were about the same.

Nutrient Exports

Flow-normalized transports of TotP and TotN revealed less temporal variation in monthly transport than the actual ones (Figs. 3 and 4). Using the criteria for the standardized test statistics as the interval between -2 and +2, and for the P values the interval between 0.025 and 0.975, no trend was found in the flow-standardized transports during this relatively short period of eight years. This was to be expected as no pronounced change in agricultural practices has taken place in this part of the

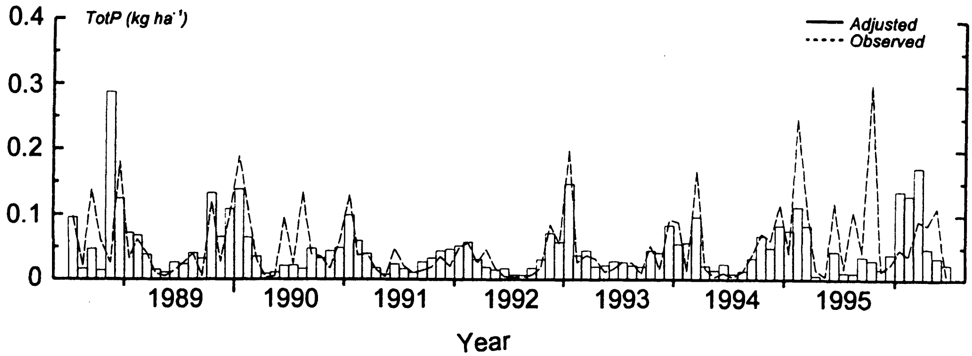

Fig. 3. Monthly flow-normalized exports of of total phosphorus (Tot-P) from the Tubbetorp catchment, 1988-1996.

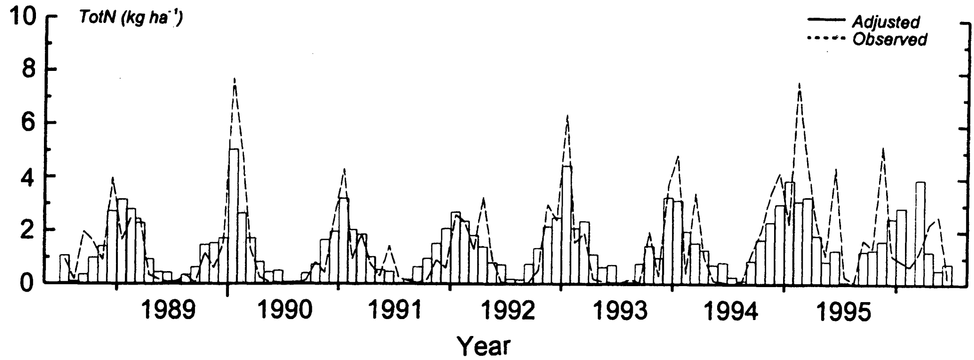

Fig. 4. Monthly flow-normalized exports of of total nitrogen (Tot-N) from the Tubbetorp catchment, 1988-1996.

country. Commercial P fertilization has decreased from 11 to 8 kg ha^{-1} while the N fertilization has been kept constant (Statistics Sweden 1990, 1992, 1994 and 1996). The area of autumn sown crops has increased by a few per cent (Yearbooks of agricultural statistics 1989-1996) and the area of winter cover crops (mainly ley, winter cereals and winter rape) just reach the target of 50%, the value that the Swedish parliament stipulated for this part of Sweden. Even pronounced changes in agricultural practices have not led to a reduction in nutrient exports from catchments for several years due to retardation and transformations of the nutrients in the soil and in the water. Thus, when studying the water quality response for nine years in river waters in Latvia, Stålnacke *et al.* (1997) did not find any improvement in water quality despite a very dramatic reduction in the use of fertilizer; similar results were found in Poland (Tonderski *et al.* 1997).

Yearly mean concentrations (1992-1996) of SS in the drainage water from the experimental plot were 13, 18, 28 and 38 mg l^{-1}, thus showing considerable variation.

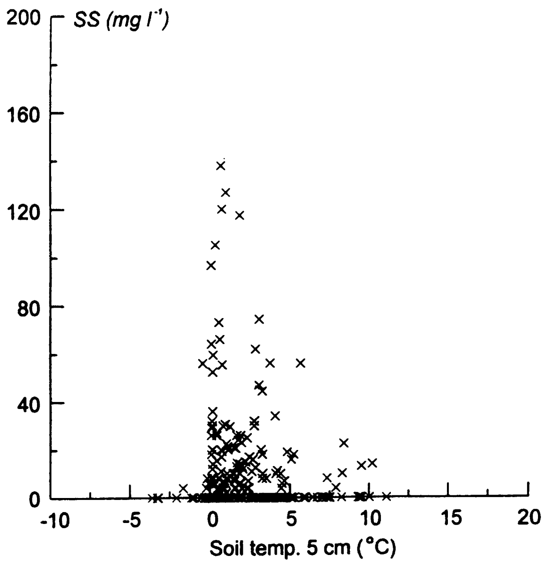

Fig. 5. Daily concentrations of suspended solids (SS) in drainage water from Lanna experimental plot together with soil temperature during winter periods (October-April) 1992-1996.

However, the standard deviations were reasonably similar (49, 46, 44 and 42 repectively). High concentrations occurred at a soil temperature interval just above zero (Fig. 5), sometimes in connection with high waterflow. Present P loss models are ususally based on erosion models. When modelling transport of PartP through drainage pipes, a simple sub-model "Partle-P" was added to the GLEAMS model asuming a yearly constant SS concentration in the transport from the soil surface (Shirmohammadi *et al.* 1998). In this way long-term averages of phosphorus losses through drainage tiles could be predicted. This sub-model would probably be improved by taking the variability of SS concentration into account and thereby allowing the prediction of more event based transports.

In the streams the concentrations of SS were usually highest during warmer conditions with less water in the streams. The concentrations were also higher than in the drainage pipes. On a catchment scale, results from ^{137} Cs-techniques (Elliot *et al.* 1984; Walling and Quine 1994) would probably improve our understanding of the transformation of erosion material. An improved sampling strategy in the streams is also highly desirable to obtain a reliable measure of erosion and nutrient losses in small areas. Discrete and sparse sampling techniques may seriously underestimate transport loads (Øygarden and Botterweg 1998).

In the present investigatiion, much of the nutrient export occurred during two wet years 1993-1994 and 1994-1995. During the 12 wettest months of this period, representing 13% of the time series, more than a third of all P and N was exported. Daily

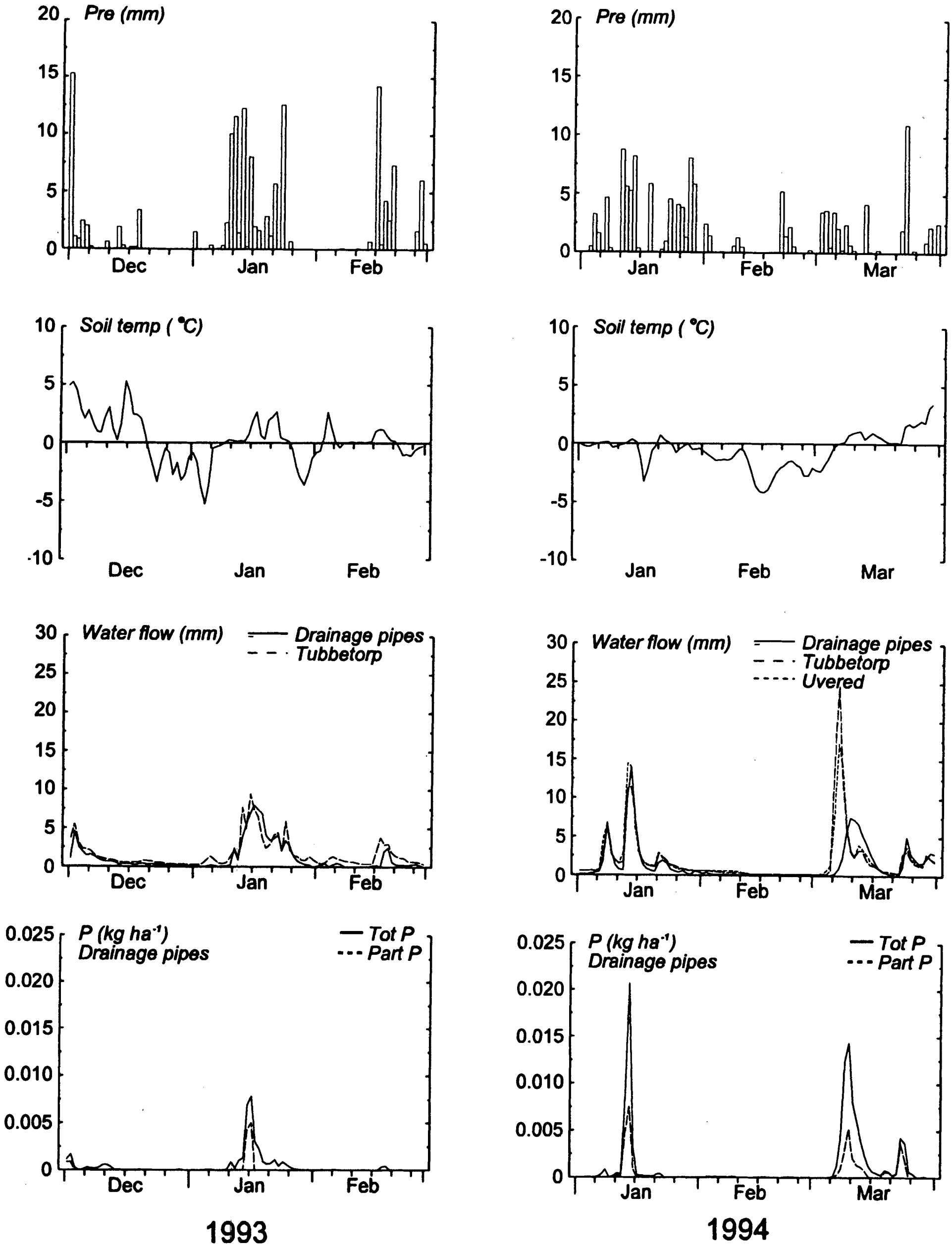

Fig. 6. Precipitation, soil temperature, waterflow and exports of total phosphorus (TotP) and particulate phosphorus (PartP) in drainage pipes, and in the streams of Uvered and Tubbetorp during Dec 1992-Feb 1993 and Jan-Mar 1994.

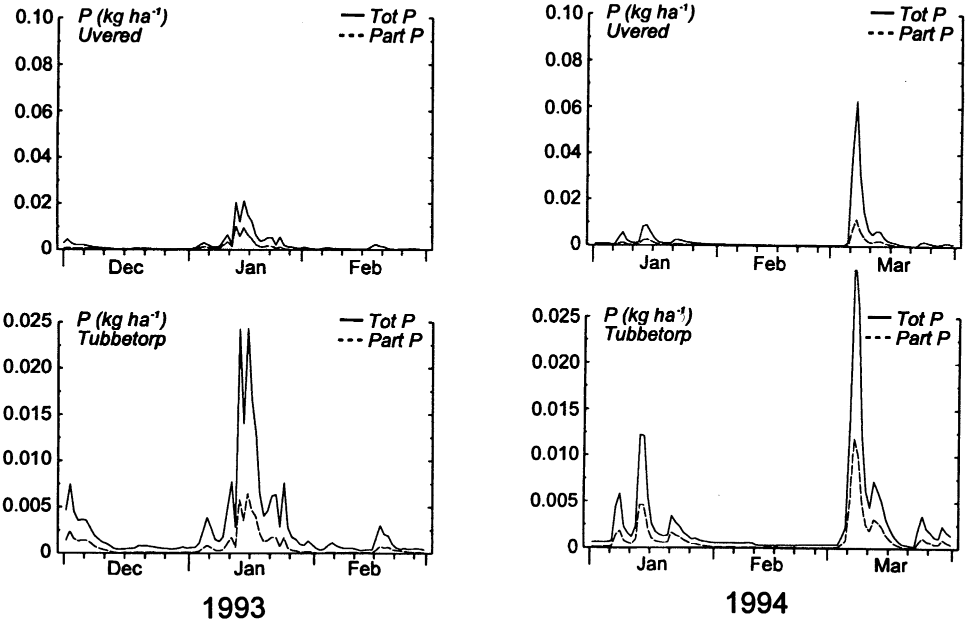

Fig. 6. **cont.**

precipitation, soil temperature and daily P export from drainage pipes and from the two watersheds are shown for periods including those of most intensive export in Figs. 6 and 7. Runoff was usually only slightly higher in the streams than in the drainage pipes but the transport of P was markedly higher. This is especially striking as the manual sampling in the stream, which was done once a week, was insufficient, in contrast to the sampling from the drainage pipe from the experimental plot. The contribution of surface soil erosion from arable land is probably of minor importance due to the very flat topography and the fact that no overland flow had been observed on the fields. However, erosion in the ravine itself may occur. Rapidly increasing flow may also cause intense erosion of the stream channels or banks. This could explain the high PartP transports in December 1994 and February 1995 (Fig. 7). However, during other pronounced runoff events, for example those in 1993 and 1994, much of the transported P in the streams was in dissolved form (Fig. 6). Nor was any relationship found between water flow and the concentration of PartP which is consistent with the findings of Ng *et al.* (1993). As pointed out by Nelson *et al.* (1996) several processes, like desorption, dissolution and mineralization, may contribute to the dissolved P in watercourses. Increased P concentrations in agricultural streams were noted in clay soil areas (Ulén 1992) where desorption is probably especially important since clay material offers many desorption sites. Phosphorus may, on the other hand, also be retained by deposition, adsorption, precipitation and

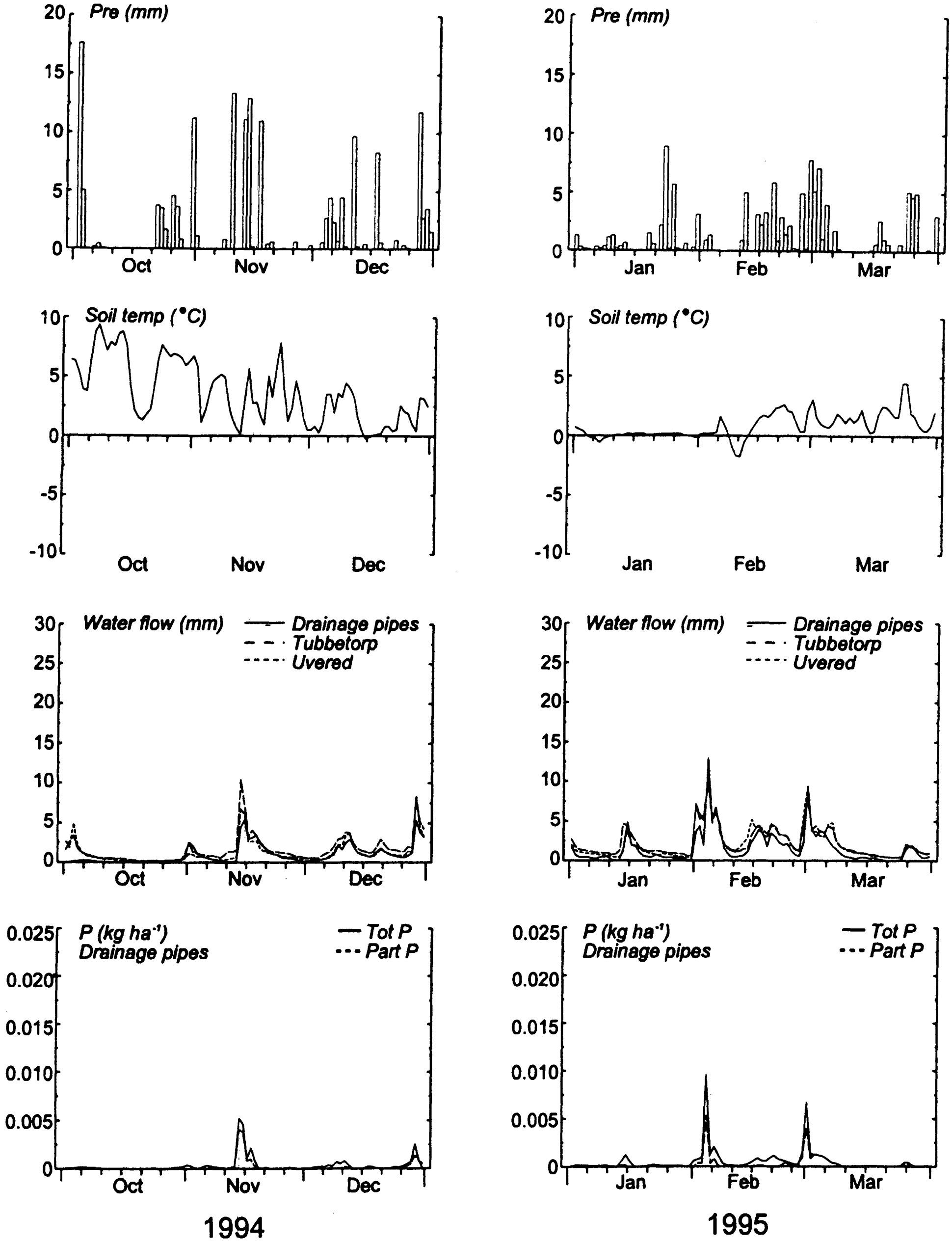

Fig. 7. Precipitation, soil temperature, waterflow and exports of total phosphorus (TotP) and particulate phosphorus (PartP) in drainage pipes, and in the streams of Uvered and Tubbetorp during Oct-Dec 1994 and Jan-Mar 1995.

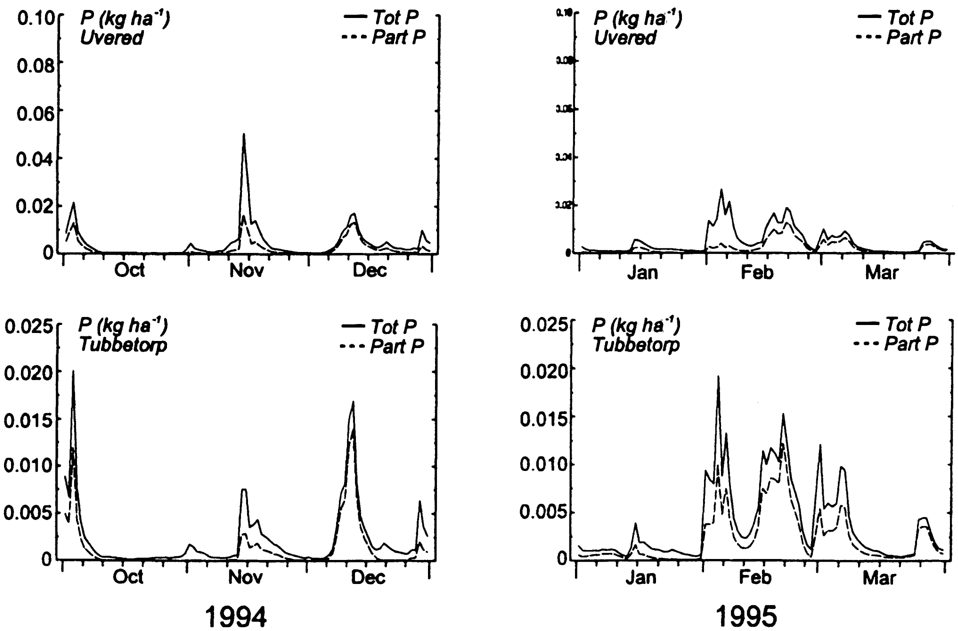

Fig. 7. **cont.**

biological uptake. Due to the lack of knowledge concerning all processes taking place in the watercourses, a source separation of P measured in brooks and streams would be difficult. Thus P exports from agricultural watersheds after reductions caused by point sources should not automatically be attributed to P losses from agricultural land. Further investigations should be conducted on the fate of P at the interface between drainage pipes and surface water and on processes in the watercourse.

Summary

Two drained agricultural watersheds showed very similar nutrient-export responses. No trend was found during eight years. A few events dominated annual yields. Yearly variation in the concentration of suspended solids from drainage pipes should be considered when developing phosphorus models. In both catchments, erosion in the ravine and in-stream processes appeared to influence phosphorus export from agricultural streams. Such processes seem to be of minor importance for nitrogen export.

References

Beck, M. B. (1996) Transient pollution events: acute risks to the aquatic environment, *Wat. Sci. Tech., Vol. 33,* No 2, pp 1-15.

Claesson, S., and Steineck, S. (1991) Plant nutrient management and the environment, Swedish University of Agricultural Sciences, SLU, Uppsala Special Report 41, 1991, in English 1996.

Dillon, P. J., and Kirchner, W. B. (1975) The effect of geology and land use on the export of phosphorus from watersheds, *Water Research, Vol. 9,* pp 135-148.

Elliott, G. L., Campbell, B. L., and Loughran, R. J. (1984) Correlation of erosion and erodibility assessments using Caesium-137, *J. Soil Cons. N.S.W., Vol. 40,* pp 24-29.

Egnér, H., Riehm, H., and Domingo, W. R. (1960) Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustanden des Böden. II Chemische Extraktionsmethoden zur Phosphor- und Kaliumbestimmung, *Ann Landw, Hochsch. Swedens, Vol. 26,* pp 199-215.

Grant, R., Laubel, A., Kronvang, B., Andersen, H. E., Svendsen, L. M., and Fuglsang, A. (1996) Loss of dissolved and particulate phosphorus from arable catchment by subsurface drainage, *Wat. Res., Vol. 30,* pp 2633-2642.

Hergert, G. W., Bouldin, D. R., Klausner, S. D., and Zwerman, P. J. (1981) Phosphorus concentration- Water flow interaction in tile effluent from manure land, *J. Environ. Qual., Vol. 10,* pp 338-344.

Kyllmar, K., Johansson, G., and Hoffman, M. (1995) Avrinning och växtnäringsförluster från JRK:s stationsnät för agrohydrologiska året 93/94 samt en långtidsöversikt, Ekohydrologi 38 Division of Water Management, Swedish University of Agricultural Sciences, pp 1-31 (in Swedish).

Naturvårdsverket (1995) Vad innehåller avlopp från hushåll? Report from the Swedish Environment Protection Board, No. 4425.

Nelson, P. N., Cotsaris, E., and Oades, M. J. (1996) Nitrogen, phosphorus and organic carbon in streams draining two grazed catchments, *J. Environ. Qual., Vol. 25,* pp 1221-1229.

Ng, H. Y. F., Mayer, T., and Marsalek, J. (1993) Phosphorus transport in runoff from a small agricultural watershed, *Wat. Sci. Techn., Vol. 28* No 3-5, pp 451-460.

Rekolainen, S., Ekholm, P., Ulén, B., and Gustafson, A. (1997) Phosphorus losses from agriculture to surface waters in the Nordic Countries. In (H. Tunney, O. T. Carton, P. C. Brooks, and A. E. Johnston (eds) *Phosphorus loss from soil to water.* CAB international Wallingford, New York, Nairobi, Kualalumpur and Curepe, pp 77-93.

Schindler, D. W. (1977) Evolution of phosphorus limitation in lakes, *Sciences, Vol. 195,* pp 260-262.

Schreiber, J. D., Smith, S. jr, and Cooper, C. M. (1996) The occurrence, distribution and remediation of transient pollution events in agricultural and silvicultural environments, *Wat. Sci. Techn., Vol. 33,* No 2, pp 17-26.

Shirmohammadi, A., Ulén, B., Bergström, L. F., and Knisel, W. G. (1998) Simulation of nitrogen and phosphorus leaching in structured soil using GLEAMS and a new submodel, Partle. Accepted for publication in Transaction of the American Soc. of Agriculture and Engineering.

Skaggs, R. W., Brevé M. A., and Gilliam, J. W. (1994) Hydrologic and water quality impacts of agricultural drainage. Critical Rev. in *Environ. Sci. and Technol., Vol. 24,* pp 11-32.

Statistics Sweden (1992-1996) Use of fertilizer and manure in agriculture 1987/88, 1990/91, 1992/93 and 1994/95. *Statistics Sweden* Na 30 SM no:s 9001, 9201 9401 and 9602.

Stålnacke, P., and Grimvall, A. (1997) Semiparametric approaches to flow-normalisation and sources apportionment of substances transport in rivers, *submitted to Environmetrics.*

Stålnacke, P., Grimvall, A., and Laznik, M. (1997) Water quality response to the dramatic reduction in the use of fertilisers in Latvia, submitted to *Ecological Modelling.*

Swedish Standard (1990) Kemiska vattenundersökningar. Katalog över Svensk standard. *Standardiseringskomissionen i Sverige,* 588 pp (in Swedish).

Tonderski, A., Grimvall A., and Sundblad, K. (1997) Impact of recent changes in agricultural practicies in Poland on the riverine transport of nitrogen. Manuscript *submitted to Ambio.*

Ulén, B. (1992) Närsaltsförluster från mindre avrinningsområden inom jordbrukets recipientkontroll i Sverige. Ekohydrologi 29, Division of Water Management, Swedish University of Agricultural Sciences, pp 5-10.

Ulén, B. (1995) Episodic precipitation and discharge events and their influence on losses of phosphorus and nitrogen from tile drained arable fields, *Swedish J. of Agric. Res., Vol. 25,* pp. 25-31.

Walling, D. E., and Quine, T. A. (1994) Use of fallout radionuclide measurements in soil erosion investigations. In Nuclear Techniques in Soil-Plant Studies for Sustainable Agriculture and Environmnetal Preservation, International Atomic Energy, Vienna, pp 597-619.

Yearbooks of agricultural statistics (1989-1996) *Official Statistics of Sweden.*

Øygarden, L., and Botterweg P. (1998) Measuring non-point pollution in agricultural watersheds in the Nordic countries. A guide for good measurement practices. *TemaNord.* Nordic Council of Ministers Copenhagen (in press).

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