Viesturs Jansons
Ritvars Sudars
Inta Dzalbe
Nils Vagstad
Johannes Deelstra
Dace Kirsteina

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Nutrient Losses from Point and Diffuse Agricultural Sources in Latvia

Viesturs Jansons [1], Nils Vagstad [2] , Ritvars Sudars [1], Johannes Deelstra [2], Inta Dzalbe [1], Dace Kirsteina [1]

Abstract

Reduced pollution of surface waters by nutrients is the expressed objective of several international conventions, e.g. HELCOM, OSPARCOM, and this task is also supported by EU directives and HELCOM recommendations. Thus, it was of great importance that a monitoring programme similar to the existing ones in the Nordic countries (e.g. Norway and Sweden) was implemented which specifically aimed at assessing the impact of agriculture on the surface water quality in Latvia. Leaching and runoff losses of nitrogen and phosphorus were measured in several agricultural catchments during the period 1994-1999. This article provides information on temporal and spatial trends of nutrient loads that may be associated with the anthropogenic impact of agriculture. The losses varied considerably depending on land use and farming practices. In catchments characterized by cereal production and moderate inputs of plant nutrients, the diffuse losses were found to be at a low level (e.g. 5-20 kg N ha^{-1} per year), as compared to measurements in similar catchments in Nordic countries. Due to the economical problems during the current transition period to market economy in Latvia, most of the new private farmers do not apply intensive farming methods. Therefore, diffuse pollution from private family farms is still low compared with most of the western countries. However, very large leaching and runoff losses were recorded in three catchments characterized by heavy applications of pig slurry and where the amounts of applied manure significantly surpassed the fertilizer requirements of the crops. In one of these catchments, high losses were recorded even though farming activities ceased in 1991/92. The study shows that the former Soviet-type large farms that specialized in animal production may still constitute potential risks for the environmental quality of inland waters in Latvia and of the Baltic Sea.

Key words: drainage, land use, monitoring, nitrogen, nutrient balance, nutrient run-off, phosphorus, water quality

[1] Latvia University of Agriculture, Department of Environmental Engineering and Water Management. LV-3001 19 Akademijas, Jelgava, Latvia. Tel. +371 302990, Fax +371 3022180, e-mail: viesturs@cs.llu.lv

[2] Jordforsk, Centre for Soil and Environmental Research. N-1432 Aas, Norway

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Zusammenfassung

Nährstoffverluste aus punktuellen und diffusen landwirtschaftlichen Quellen in Lettland

Es ist das erklärte Ziel mehrerer internationalen Konventionen wie z. B. HELCOM und OSPARCOM, die Nährstoffbelastung von Oberflächengewässern zu verringern. Dies findet auch Berücksichtigung in EU-Direktiven und Empfehlungen der HELCOM. Deshalb ist es von grosser Bedeutung, dass in Lettland ein Überwachungsprogramm eingerichtet wurde, das ähnlich existierenden Programmen in skandinavischen Ländern (z. B. in Norwegen und Schweden), die Auswirkungen der Landwirtschaft auf die Qualität von Oberflächengewässern untersucht. Die Auswaschung von Stickstoff und Phosphor wurde in mehreren Niederschlagsgebieten im Zeitraum zwischen 1994 und 1999 gemessen. Der vorliegende Beitrag gibt einen Überblick über zeitliche und räumliche Trends von Nährstoffbelastungen in Oberflächengewässern, die auf landwirtschaftliche Aktivität zurückgeführt werden können. Die Untersuchung zeigt, dass Landnutzung und Bewirtschaftungsform die Nährstoffauswaschung stark beeinflussen. Im Getreidebau Lettlands, der durch mässige Nährstoffzufuhren gekennzeichnet ist, ist die diffuse Nährstoffauswaschung - verglichen mit anderen nordischen Ländern - gering (z. B. 5-20 kg N ha^{-1} und Jahr). Wegen der wirtschaftlichen Probleme, denen Lettland in der Übergangsperiode zur Marktwirtschaft ausgesetzt ist, werden die landwirtschaftlichen Flächen weniger intensiv bestellt. Deshalb ist, verglichen mit den meisten westlichen Ländern, die diffuse Verunreinigung durch private landwirtschaftliche Betriebe nach wie vor gering.

Hohe Nährstoffauswaschung wurde jedoch in drei Niederschlagsgebieten festgestellt, in denen mit grossen Mengen an Schweinegülle gedüngt wurde und wo die applizierte Menge Dünger bei weitem die Erfordernisse der Pflanzen übersteigt. In einem der untersuchten Niederschlagsgebiete wurden hohe Nährstoffverluste registriert, obwohl die landwirtschaftliche Nutzung 1991/92 eingestellt wurde. Die Untersuchung zeigt, dass grosse landwirtschaftliche Kooperativen, wie sie zur Zeit der Sowjetunion existierten, nach wie vor ein Umweltrisiko für Binnengewässer in Lettland und für die Ostsee darstellen.

Schlüsselwörter: Abfluß, Landnutzung, Monitoring, Nährstoffaustrag, Nährstoffbilanz, Stickstoff, Wasserqualität

1 Introduction

After the disintegration of the former Soviet Union in 1990/91, Latvia went through dramatic changes in all sectors of society. This also resulted in complete changes of the agricultural sector. The Soviet system was strictly production oriented and heavily subsidized, with low resource use efficiency, i. e. crop yields were low compared to the inputs of nutrients through fertilizers and animal manure (Løfgren *et al.,* 1999). Another result of this production system was that the environmental impact of agriculture was insufficiently considered. Lack of reliable monitoring data for the estimation of diffuse agricultural pollution sources was a common problem in post-Soviet countries, including Latvia. Due to the joint Baltic-Nordic projects and networks these had created, it was possible to establish an agricultural run-off monitoring program in Latvia in 1994. This program has been of great importance for the preparation of relevant national legislation and more stringent measures to reduce emissions from agriculture. However, this does not imply that national authorities are not willing to reduce pollution, but measures are generally decided on the basis of available scientific information about the state of pollution from agriculture.

Previous Soviet-type agriculture caused a lot of problems associated with storage and spreading of animal manure and commercial fertilizers. Many large and specialised collective farms were established in different parts of Latvia during the 1970s and 1980s. Pig farms with capacities up to 50.000 slaughter pigs per year were built. Consequently, the amounts of manure applied often surpassed the fertilizer requirements of the crops, leading to an increased risk of phosphorus accumulation in soils, and runoff and leaching of plant nutrients to rivers and lakes. The number of large livestock farms and the total number of animals decreased drastically since 1993. A few state farms survived, but were divided into smaller specialised share companies. The buildings and equipment are used as previously, but the available land area for cultivation and manure application was drastically reduced due to privatisation, and thus even more serious problems regarding manure handling were created (Haraldsen T.K. et al., 1998).

Most of the state and collective farms in Latvia have been privatized since 1993. A major part of the land previously belonging to state farms has been re-divided into smaller farms, according to the ownership rights in 1940. The consumption of commercial fertilizers and pesticides declined by about 90 % since 1990, reaching the lowest level in 1993. Due to the economical problems during the transition period, generally new private farmers are not able to apply intensive and modern farming methods. However, the application of fertilizers, pesticides and modern technology has slightly increased since 1994. The level of environmental knowledge, lack of experience and low technology in the private farms may cause environmental problems in the nearest future. Based on existing and historical conditions, and on the agro-climatic potential for agriculture in Latvia, it is believed that economic forces will enhance the development towards a more intensive agriculture. In that situation, environmental monitoring, as well as environmental education and legislative measures will have utmost importance to decrease negative impacts of agriculture (Vagstad et al., 2000).

This paper presents the results of point and diffuse source nutrient load measurements in 6 different catchments in Latvia during 1994-1999.

2 Materials and Methods

2.1 Description of Monitoring Sites

The inland water bodies receive nitrogen and phosphorus emissions, which are a net result of both diffuse and point source pollution. In an assessment of diffuse agricultural pollution, it is crucial to be able to control nutrient balances and exclude other loads, i.e. from point sources: large livestock farms and wastewater from households. Therefore, a diffuse source monitoring programme (Jansons, 1998) in Latvia was implemented in 3 small agricultural catchments (Berze, Mellupite and Vienziemite streams) with ordinary agricultural practice and in 3 drainage fields within these catchments, see Figure 1. In addition, a specific monitoring programme was established in 3 catchments (Vecauce, Ogre and Bauska farms) representing large pig farms as point sources, with high rates of animal manure (slurry) application. A description of monitoring sites is presented in Table 1.

The soils at the monitoring sites are imperfectly to poorly drained. Most of the agricultural land in the small catchments is drained with tile drains (depth 1.1 – 1.3 m, and internal spacing between drains 10 – 32 m). Tile drainage in drainage fields, except for the Bauska farm, has surface run-off inlets, which may result in direct inflow of eroded soil particles during flood periods.

Due to the presence of a calcareous material soil pH is rather high ($p^{H}H_2O$ = 6.7-7.9). The status of major plant nutrients ranges from good (Berze site: C_{org} = 1.2 mg $100g^{-1}$, N = 0.15 %, P_{Al} = 10.5 mg $100g^{-1}$) to moderately good (Mellupite site: C_{org} =1.2 mg $100g^{-1}$, N = 0.08 %, P_{Al} = 8,3 mg$100g^{-1}$).

3 Climate and Hydrology

Latvia is situated in a humid and moderately mild climatic region where rainfall exceeds evaporation, resulting in percolation losses in the soil during spring and autumn. The precipitation is higher in the western and north-eastern parts of Latvia (700-800 mm $year^{-1}$) than in the cen-

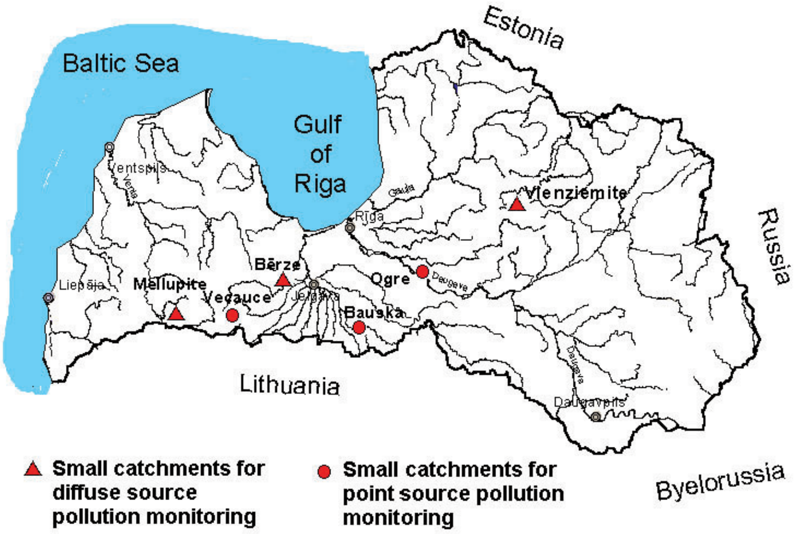

Fig. 1
Agricultural run-off monitoring sites in Latvia

Table 1
Description of the agricultural run-off monitoring sites in Latvia

Station	Area, ha (% cultivated)	Flow measurement Sampling method	Main soil type	Description of agricultural system
Diffuse pollution monitoring stations / small agricultural catchments				
Vienziemite				
Small catchment	592 (78)	Data logger Manual sampling	Sandy loam	Low input farming, arable crops 4-5 % within catchment area.
Drainage field	67 (100)	Recorder Manual sampling		Low input farming, mixed crops.
Mellupite			Loam, clay loam	Moderately intensive farming representing intensive farming arable crops 35-45 % in catchment area.
Small catchment	960 (69)	Data logger, Flow prop. sampling		
Drainage field	12 (100)	Data logger Flow prop. sampling		Intensive grain farming.
Berze				
Small catchment	368 (98)	Data logger Manual sampling	Silty clay loam	Intensive grain farming, arable crops 80-90 % within catchment area.
Drainage field	77 (100)	Recorder Manual sampling		Intensive grain farming.
Point source pollution monitoring sites / high animal density areas				
Vecauce				
Small catchment (incl. slurry application fields)	60 (90)	Flow modelling Manual sampling	Sandy loam	Intensive grain farming, arable land 80 %. Slurry application on 30 ha within catchment.
Bauska				
Small catchment (incl. pig farm)	800 (95)	Flow modelling Manual sampling	Silt loam	Intensive farming, mixed crops. Slurry dumping site -50 ha field and pig farm within catchment. Grassland in the slurry dumping field.
Ogre				
Small catchment (incl. former pig farm)	300 (25)	Flow modelling Manual sampling	Silty clay loam	Moderately intensive farming, old slurry lagoons and polluted territory of former pig farms within catchment, farm closed in 1992.

tral part of the country and in coastal areas (550-600 mm $year^{-1}$). Winters are cold with average temperatures in January varying from –2.6 ^{o}C along the western coast to –7.4 ^{o}C in the northeast. The greatest snow depths are observed in the eastern and north-eastern part of the country (20-40 cm), with a duration of about 4 months. A stable snow cover is not established every year in the central part. The summer is temperate with the highest average temperatures in July (15.9 - 17.1^{o}C). The precipitation for 1994-1999 is characterised by a "dry" year in 1996, normal years in 1994 and 1999, relatively "wet" years in 1995 and 1997, and a wet year in 1998.

The hydrological regime in Latvia is typical for many of the East-European regions. The subsurface drainage runoff is about 200 mm in a normal year. The maximum flow in rivers usually occurs during spring flood. About 50 % of the annual runoff is generated from snowmelt in spring, 30 % from rainfall events and 20 % from groundwater discharge during low flow periods. The Vecauce area is an exception with the higher groundwater discharge resulting in the higher run-off from the catchment than under normal water balance conditions. Both extreme deviations from normal values were observed in runoff measurements in the period 1994-1998. The year 1996 was "driest" since 1974 (126 mm $year^{-1}$ in theVienziemite monitoring site) and 1995 was a "wet" year with 467 mm run-off in the Vienziemite monitoring site.

4 Measurement Programme

The runoff measurements and water samplings were carried out in small streams or drainage field outlets of the small catchment areas. Water analyses were carried out in Latvia according to standard methods. The Latvian laboratory achieved satisfactory precision in intercalibration tests against a Norwegian laboratory (Jordforsk). The parameters analysed included total N, NO_3-N, NH_4-N, total P, PO_4-P, pH, Ca, Na, Mg and K. Soil analyses were performed in Norway (Jordforsk) according to the standard methods.

The measurements in the Berze, Vienziemite and Mellupite catchments were based on fixed measurement structures, i. e. Crump, V-shape and combined profile weirs and automatic data loggers and sampling equipment for continuous water level registration and water sampling (only in the Mellupite catchment). Composite water samples were collected based on a flow proportional sampling procedure. Nutrient runoff was calculated by multiplying the nutrient concentrations of the individual water samples with the total volume of water that was discharged during the corresponding sampling period. The measurements started in the Berze and Vienziemite catchments in 1994 and in the Mellupite catchment in 1995.

The measurements in Bauska, Ogre and Vecauce were based on manual water sampling at regular intervals (once per month). Water discharge was simulated, using the Latvian developed METQ96 model. Nutrient runoff was calculated by multiplying the interpolated daily concentrations of two subsequent samples with daily discharge simulated by METQ96. Water sampling in slurry application sites started in 1995.

5 Results

5.1 Land Use and Management Practices

The catchments are located in different regions of Latvia with varying climate, soil, slopes, crops and market conditions.

The Berze catchment is characterised by relatively intensive crop production as compared to the present average conditions in Latvia. The landscape is flat lowland and 98 % of the catchment soils are cultivated. Due to natural high soil fertility, winter wheat and sugar beets have become the main crops in the Berze catchment. The share of arable crops increased up to 80-90 % during 1997-1999. Farmers are using modern equipment, and rather intensive technology for Baltic conditions, e. g. a fertilizer application in few fields reached 160 kg N ha^{-1} $year^{-1}$ in 1999.

The landscape in the Vienziemite catchment is rather hilly for Baltic conditions. Soil, slopes, market conditions are less favourable for agriculture and only two farms in the catchment are producing something for market. Almost no fertilizers (only 4 - 5 kg N ha^{-1} $year^{-1}$) were applied in Vienziemite. Most of the farmland was abandoned land or low productivity grassland during the measurement period 1994-1999. The Vienziemite catchment is a typical example of low input agricultural land use, and can be used as a reference site for diffuse pollution.

The Mellupite catchment represents average farming conditions and could be considered typical for the present agriculture in Latvia. Several large farms are using intensive agricultural technology, whereas a few farms are producing only for self-consumption with low fertilization rates and without pesticides. The average use of mineral fertilizers ranges from 10 - 40 kg N ha^{-1} $year^{-1}$. From 1994 to 1999 the use of fertilizers and pesticide increased slowly.

The Bauska, Vecauce and Ogre catchments were previously part of large state and collective farms that specialised in pig production, and can be characterised by large applications of animal manure (slurry) during the Soviet period. The Ogre farm was closed in 1992 after 15 years of production. The farm produced 30, 000 pigs per year. Primitive earth lagoons were used for slurry storage and they still remain full of slurry. Soils surrounding the Ogre farm received large amounts of slurry during 1977 - 1991, usually applied by tractor tankers and sprinkler irrigation (on 240 ha of land).

The Bauska farm was established in 1970 and reached full production (12.000 fattening pigs per year, 55.000 m^3 pig slurry per year) in 1976. After use of tractor moved tankers for slurry application, a slurry irrigation system was constructed in 1987. Today the pig production is about 8.000-10.000 fattening pigs per year, but the slurry utilization area is only 50 ha, due to the changes in land use following privatization. Slurry has been applied on grassland fields throughout the entire year. On average, 900 m^3 of slurry has been applied per ha and year, representing a nutrient supply of approximately 630 kg total N ha^{-1} and 80 kg P ha^{-1}.

The Vecauce pig farm was established in 1987 for the production of 6.000 fattening pigs per year. After separation, the liquid manure was stored in a lagoon and used for irrigating an area of 32 hectares. Since 1991, the farm produced 1, 500-2.000 pigs per year and up to 250 m^3 pig slurry per hectare and year has been applied to this catchment by irrigation.

6 Nutrient Concentrations

Nutrient concentrations in runoff for six monitoring sites are presented in Table 2. The results are presented as mean and maximum values and coefficients of variation for all water samples during the monitoring period. The “background values” for nutrient concentrations presented in Table 2 are based on measurements in sampling points with low input agriculture (small acreage of arable land and no fertilization). The target concentrations for catchments with intensive agriculture are based on the Swedish programme target to fulfil the HELCOM goal for a 50 % reduction of the nutrient inputs to the Baltic Sea.

The nitrogen concentrations in the two catchments (Vienziemite and Mellupite) are relatively low. The total-N concentrations in the Berze catchment exceed 5 mg l^{-1} and could be considered as moderate. Higher total-P concentrations (0.23 mg l^{-1}) in the Berze can be related to soil erosion. Finally, it should be noted that nitrogen and especially phosphorus concentrations in the high animal density areas (Bauska, Ogre) are several times higher than in small agricultural catchments (Berze). Moreover, it must be recognized that concentrations of phosphorus are higher than criteria (emission limit value 1 mg l^{-1} P_{tot}) set for wastewater after treatment in Latvia.

Table 2
Concentrations of nutrients in monitoring catchments (1994-1999)

Monitoring site	N of samples	N-NO_3 mg l^{-1}			N_{tot} mg l^{-1}			P_{tot} mg l^{-1}		
		Mean	Maximal	CV %	Mean	Maximal	CV %	Mean	Maximal	CV %
Diffuse pollution monitoring stations / small agricultural catchments*										
Vienziemite										
Small catchment	72	0.8	4.9	92	1.6	7.5	71	0.03	0.12	59
Drainage field	69	0.7	3.4	93	1.6	6.7	73	0.04	0.41	133
Mellupite										
Small catchment	53	1.7	5.4	84	2.6	6.4	56	0.06	0.37	96
Drainage field	42	4.8	10.3	46	5.6	11.1	38	0.08	1.11	204
Berze										
Small catchment	63	5.4	16.8	71	6.7	18.6	58	0.23	2.13	121
Drainage field	60	7.9	20.4	44	8.9	21.6	41	0.06	0.26	102
Point source pollution monitoring sites / high animal density areas										
Vecauce										
Small catchment	64	6.6	24.5	81	7.6	33.5	82	0.03	0.26	127
Bauska										
Small catchment	54	7.31	18.5	138	20.0	69.2	89	1.68	6.29	110
Ogre										
Small catchment	40	4.6	74.7	255	7.8	83.8	183	0.93	6.66	120

* Background concentrations: 1-3 mg l-1 N_{tot} and 0.01-0.02 mg 1^{-1} Ptot
Target concentrations for catchments with intensive agriculture: 5 mg l^{-1} N_{tot} and 0.05 mg l^{-1} Ptot

The observed N concentrations were higher in the drainage field outlets compared with concentrations in the streams. This is the result of relatively faster flow processes and less favourable conditions for nutrient retention in drainage - fast intake of surface runoff and leakage of nutrients through the soil layer to drainage pipes.

7 Nutrient Loads

The variations in nutrient run-off (Table 3) are considerable. The greatest nutrient run-off occurs in connection with the spring flood, and the lowest during the summer period. The lowest diffuse source losses were measured at the Vienziemite monitoring site where the share of arable land within the catchment was 4-5 % during 1994-1999. The highest diffuse source nutrient losses occurred in the Berze site, and exceeded by far the losses in Vienziemite. In Mellupite, where agricultural land use might be considered as moderately intensive for Latvian conditions, there is a tendency of increasing losses. The lowest losses measured were 1.8 kg N ha^{-1} year^{-1} and 0.03 kg P ha^{-1} year^{-1}, while the largest losses were 26.3 and 0.77 kg ha^{-1} year^{-1} respectively. The range off diffuse source losses was in the order of 15 times for N and 25 times for P when consider-

Table 3
Nutrient run-off from monitoring sites in Latvia 1994-1999

	N_{tot} kg ha^{-1} year^{-1}						P_{tot} kg ha^{-1} year^{-1}					
Monitoring site	1994	1995	1996	1997	1998	1999	1994	1995	1996	1997	1998	1999
Diffuse pollution monitoring stations / small agricultural catchments												
Vienziemite												
Small catchment	4.3	8.2	3.7	7.5	8.6	5.8	0.13	0.12	0.04	0.09	0.14	0.15
Field drainage	1.8	6.1	2.9	6.0	4.7	6.0	0.69	0.07	0.03	0.07	0.09	0.11
Mellupite												
Small catchment		8.1	7.1	11.2	9.6	8.3		0.23	0.14	0.10	0.24	0.27
Field drainage		16.1	11.5	19.7	20.6	15.2		0.20	0.12	0.11	0.77	0.22
Berze												
Small catchment	10.4	10.5	17.1	16.6	14.7	18.9	0.48	0.41	0.52	0.23	0.27	0.19
Field drainage	12.6	19.6	21.7	26.8	24.0	15.8	0.40	0.23	0.23	0.13	0.15	0.11
Point source pollution monitoring sites / high animal density areas												
Vecauce												
Small catchment		31.7	50.4	69.5	57.1	35.1		0.15	0.10	0.07	0.18	0.09
Ogre												
Small catchment		21.8	33.2	61.8	76.5	48.5		5.40	2.41	2.08	5.04	2.2
Bauska												
Small catchment		23.3	23.5	74.8	76.5	32.8		1.00	2.28	3.6	5.04	1.8

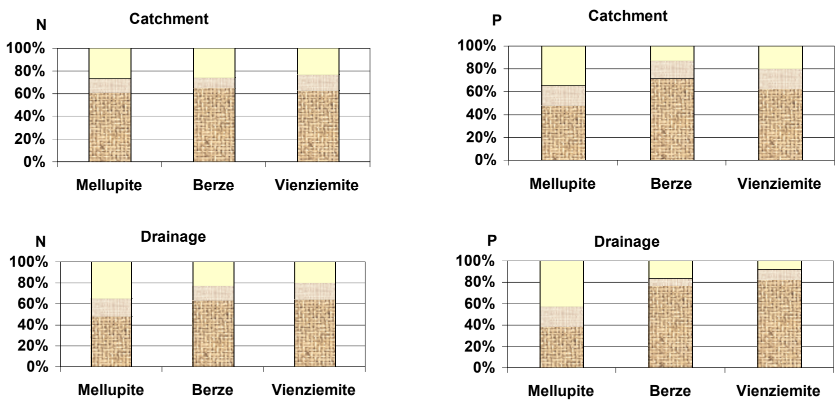

Fig. 2
Seasonal distribution of nutrient loads from diffuse sources at catchment and field drainage scale

ing the overall variation. Generally, it seems that nitrogen loads are higher from field drainage systems compared with small catchments. At the same time, phosphorus run-off, except for the Mellupite drainage field in 1998, was higher in small catchments.

The seasonal variations (Fig. 2) indicate the significance of the period January - April. Most of the river flow and more than 50 % of the nutrient loads both from catchment and drainage occur during spring flood. Occasional snowmelt in winter and rainy periods in autumn may also result in losses. Thus, specific agricultural practices and mitigation measures should be implemented to decrease the pollution risk caused by the meteorological conditions that are prevailing during the autumn/winter period.

Nutrient run-off levels in high animal density areas could be expected to be very different on local catchment scale. Both nitrogen and phosphorus loads on the Bauska and Ogre farms have been measured several times higher than in catchments with only diffuse sources.

8 Discussion

The results of the study show large variations in N and P run-off losses depending on the agricultural land management and farming practices (Fig. 3).

The diffuse source nutrient losses in the Berze and Mellupite small catchments appear to be low, as compared to the recorded losses under similar conditions in the Nordic countries (e. g. Norway and Sweden). Nitrogen losses ranged from 15-70 kg ha^{-1} year^{-1} during 1994-1997 in 8 small catchments in Norway and Sweden. Average measured nitrogen runoff was 30 kg N ha^{-1} year^{-1} (Kyllmar et al., 1996). These losses are approximately three times higher than average losses (9.7 kg N ha^{-1} year^{-1}) from Berze, Mellupite and Vienziemite small catchments, thus indicating differences in leaching regimes and agricultural practices between areas in Latvia and Nordic countries. One important factor may be the difference in fertilizer applications. In the Latvian catchments the average nitrogen application per ha of agricultural land was: 4-5 kg ha^{-1} year^{-1} in the Vieziemite catchment, 13 kg ha^{-1} year^{-1} in the Mellupite catchment and 30 kg ha^{-1} year^{-1} in the Berze catchment during 1994-1999. Although the average applications are low, some fields within the Berze catchment received 160 kg N ha^{-1} year^{-1}. Another reason for the observed differences in N losses may be different hydrological regimes, leading to longer water residence time (Deelstra et al., 1998) and therefore higher nutrient retention in Latvian catchments.

On the other hand, measurements in catchments with current or past high animal densities (including pig farms with production capacities of 10-30 thousand pigs per year) showed very high losses, with an average of 46-48 kg N and 2.7-3.4 kg P ha^{-1} year^{-1}. Data on phosphorus loads in the Bauska and Ogre catchments reflect an extreme deviation from natural water quality status, and point sources are assumed to have major impact via direct run-off of applied slurry. Moreover, in one particular slur-

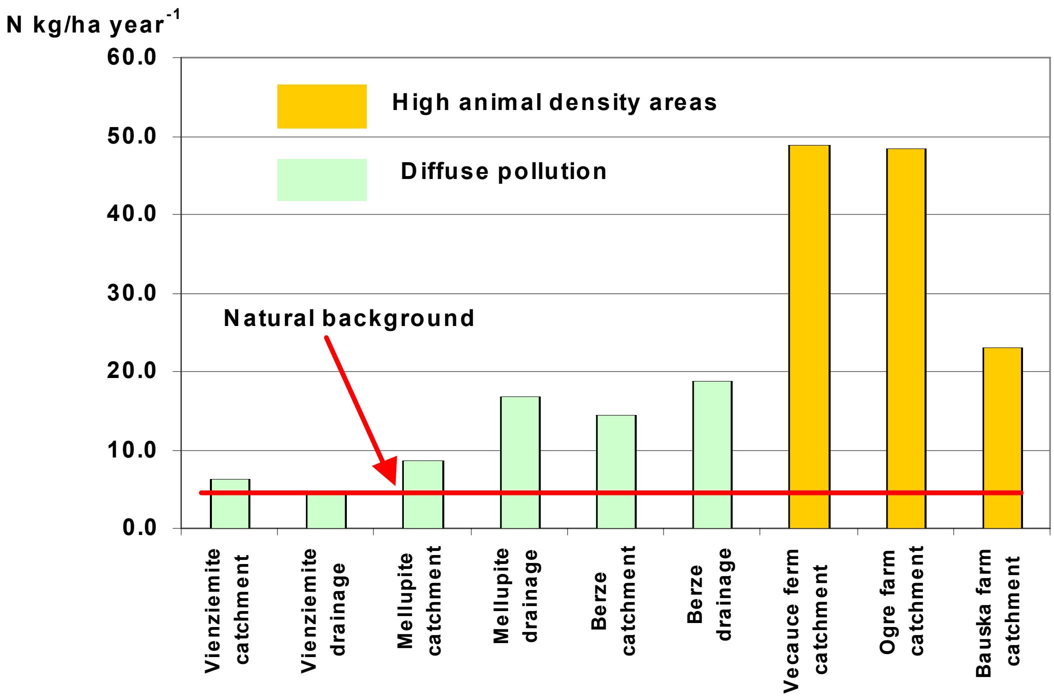

Fig. 3
Mean values of nitrogen losses from diffuse sources and high animal density areas

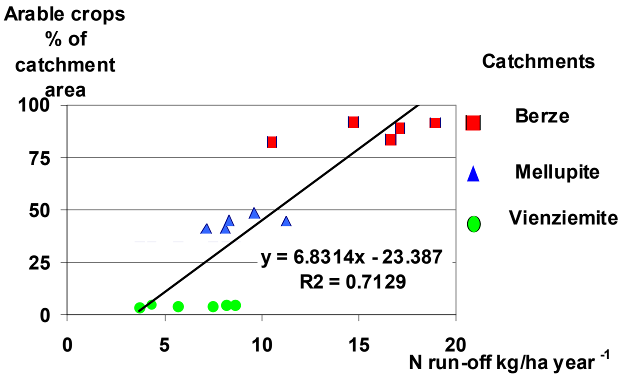

Fig. 4
Nitrogen run-off in relation to area of arable crops in small catchments

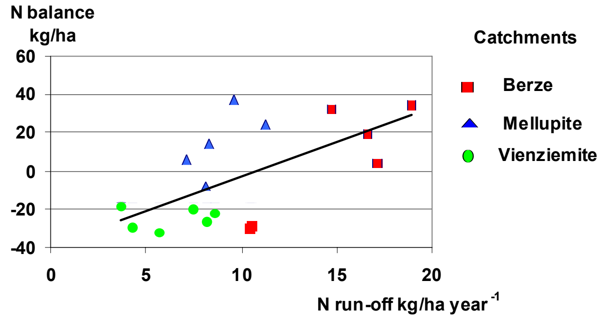

Fig. 6
Nitrogen run-off and nutrient balance at small catchment level

ry dumping field of 50 ha in the Bauska catchment, losses exceeding 10 kg P and 250 kg N ha^{-1} $year^{-1}$ were recorded. In one of these catchments (Ogre) farming activities ceased in 1991/92. Results indicate that such farm land still may function as "area point-sources" with risk of significant losses of nutrients to the aquatic environment.

The diffuse nitrogen loading from small catchments and drainage fields was compared with several variables such as area of arable land and soil surface nitrogen balance. Phosphorus loads are hard to predict, as phosphorus run-off is related both to the soil phosphorus status and occasional surface run-off and erosion events. The percentage of the land used for agriculture and, especially, the acreage of the arable crops (% fields) seems to be the most important variable explaining variations in total nitrogen loads both in small catchments and drainage fields (Fig. 4 and 5). The significance of the percentage of arable fields is higher at the drainage field level than on catchment scale.

The data indicates that diffuse nitrogen loading per ha agricultural land has trend to increase with increasing nitrogen surplus. It should also be noted that the data presented in this paper does not show statistically significant correlation of nitrogen run-off with nitrogen balance within catchments (Fig. 6). However, during the first years of run-off monitoring (1994-1995), nutrient inputs were low in all catchments. Use of fertilizers in both the Berze and Mellupite catchments has been increasing since 1996. Nitrogen loading and nutrient balance shows less variation and better correlation at the drainage field scale (Fig. 7).

Conclusions

Diffuse source of agricultural pollution varies widely and is a complex function of land use, crops and fertilization, soil type, climate, topography and hydrology. It can be concluded that the area with specific nutrient losses from agricultural catchments are relatively low in Latvia today, as compared to Norway or Sweden. However, there is a tendency of increased nutrient concentrations in run-offs. The nutrient load in 3 monitoring sites in Latvia generally depends on land use, crop and nutrient management. The effects of hydrological processes on nutrient losses add an additional dimension to the question of management strategies. Agricultural practices, such as crop rotation systems, nutrient inputs and soil conservation measures, are of course important for the site specific

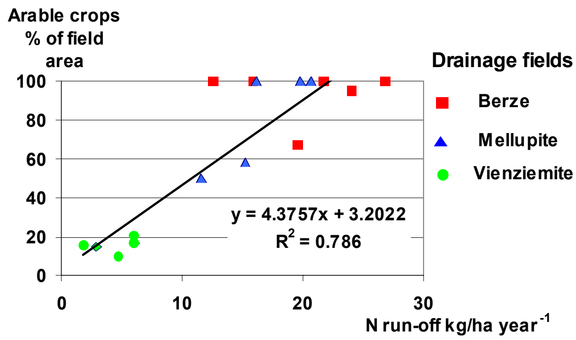

Fig. 5
Nitrogen run-off in relation to area of arable crops in drainage fields

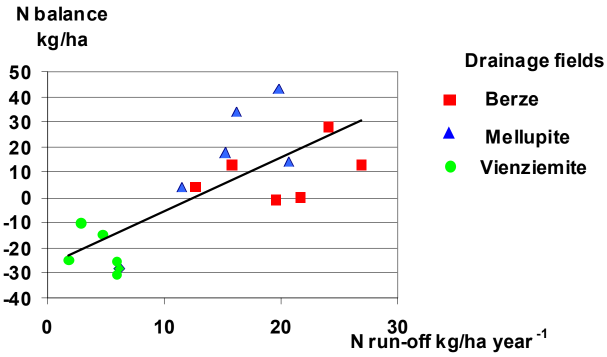

Fig. 7
Nitrogen run-off and nutrient balance at field drainage level

effects, although they can not explain the large regional differences that have been observed in this study. It is the interaction between agricultural practices and the basic catchment characteristics, including the hydrological processes, which determine the total losses of nutrients to surface waters. These processes need to be understood for efficient implementation of the control measures for diffuse agricultural nutrient losses.

Our research has shown that the previous Soviet-type, large livestock farms may be considered as important point pollution sources and are thus an important target for the minimization of negative environmental impacts of agriculture in Latvia.

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References

Deelstra J, Vagstad N, Loigu E, Vasilyev A, Jansons V (1998) Interactions between hydrology and nutrient runoff in small agricultural catchments : a comparative study of Estonian, Latvian and Norwegian catchments. In: 20th Nordic Hydrologic Conference; Vol 1, pp120-129

Haraldsen TK, Jansons V, Spricis A, Sudars V, Vagstad N (1998) Influence of long-term heavy applications of pig slurry on soil and water quality in Latvia : towards sustainable land use. Advances in GeoEcology 31: 621-628

Jansons V (1998) Latvian monitoring programme :measuring run-off and nutrient loses from agricultural land in Nordic countries. TemaNord 575: 82-84

Kyllmar K, Johansson H (1996) Discharge and nutrient losses from arable land in 1994/95 and a long term review. Ekohydrologi 40, ISRN SLU-VV-EKOHYD-40-SE, ISSN 0347-9307

Løfgren S, Gustafson A, Steineck S, Stålnacke P (1999) Agricultural development and nutrient flows in the Baltic States and Sweden after 1988. Ambio 28: 320-327

Vagstad N, Jansons V, Loigu E, Deelstra J (2000) Nutrient losses from agricultural areas in the Gulf of Riga drainage basin. J Ecol Engineering 14: 435-441