Assessment of Agriculture Impact on Water Quality with Agro-Environmental Indicators
Indikatori lauksaimniecības ietekmes uz ūdens vidi novērtēšanai

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Abstract. Farmers use many of the natural resources of the world; therefore, monitoring of sustainable resource management and environmentally friendly farming practices should be an important policy aim in Latvia. The changes in market system caused conflicts among sustainable agriculture development dimensions. There is a need, thus, to determine appropriate measuring tools and methods for the evaluation of farm sustainability that would help the policy makers make rational decisions. Nitrogen leaching from intensive agricultural systems is one of major contributors to increased nitrate concentrations in groundwater and eutrophication of surface waters. Most of the changes in water quality indicators can be directly associated with the farm management in the river basin. Our results indicate that the nitrogen balance and share of arable land in a farm have significant impact on nitrogen losses.
Key words: sustainability, farm practice, pollution, arable land, nitrogen.

Introduction

Over the centuries, agriculture has shaped the Latvian landscape. There is a growing consensus between natural and social scientists that sustainability depends on maintaining natural capital. Sustainable humanity can be achieved by maintaining the stock of the globe's natural resources. Latvia has the necessary preconditions for sustainable rural development harmonizing Latvian national interests with global development trends. Many of the natural resources of the world are used by farmers, therefore the use of environmentally friendly farming practices is an important policy aim (Dzalbe, Kiršteina, 2000; Dzalbe, 2000; Environmental Indicators …, 1999).

There are about 2.5 million ha of agricultural land in Latvia, including 1.6 million ha of drained arable land. Therefore, for a long time agriculture and food production has been the priority in Latvia. Development of agriculture is based on usage of natural resources – soil, water and biodiversity, which have significant effects on the state of the environment.

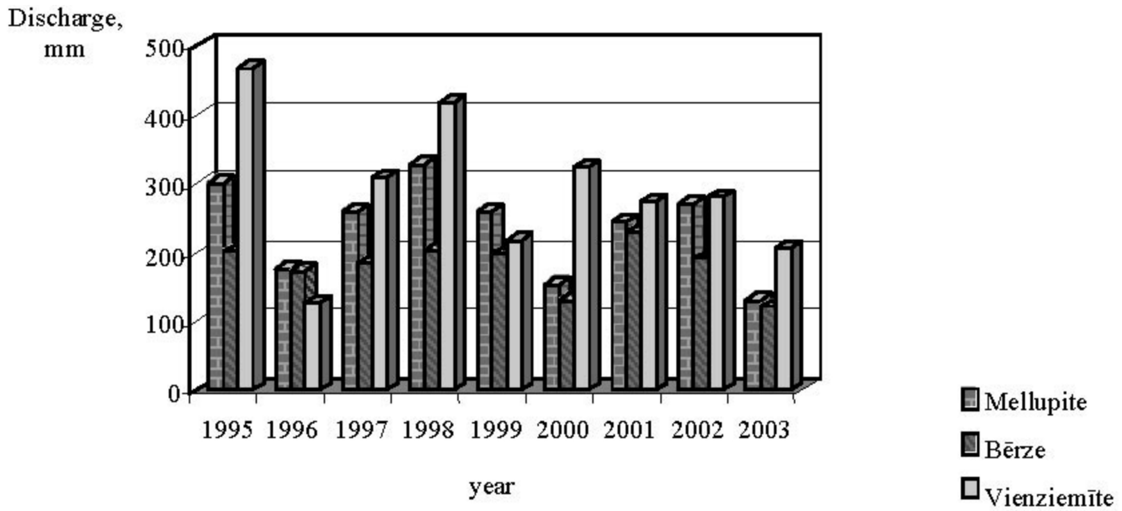
The transition process from central planning systems to the market economy includes land reform, privatization, sectoral transformation and the establishment of a new system of agriculture. Due to the economic problems during the transition period, private farmers are not able to apply intensive and modern farming methods. However, the application of fertilizers and pesticides has gradually increased since 1994.

People involved in farm management are of different competence: education, knowledge, motivation, etc. A number of farmers don't have basic agricultural education, which causes a lack of information for activities having no direct and immediate economic influence – environmental aspects, landscape, biodiversity, etc. In this situation, environmental education, information and environmental monitoring have a significant capacity to decrease the negative impact of agriculture (Bušmanis et al., 2000; 2002).

Nitrogen leaching from intensive agriculture systems is one of major contributors to increased nitrate concentrations in groundwater. Leakage and surface runoff of nitrogen and phosphorus as well as atmospheric deposition of nitrogen compounds contribute to the general eutrophication of the Baltic Sea. Eutrophication has been identified as a major cause of impaired water quality (European Environment Agency, 1998; 1999; Environment Agency, 1998; Sharpley et al., 2000). Eutrophication restricts water use for drinking and other human needs. The unbalanced ecosystem and decreased water quality make the water body unacceptable for human consumption and causes ecological problems (Jansons, 1997).

As the reaction to this, increased focus on the environmental impacts from farming attempts to develop agro-environmental indicators under the heading of sustainability. "Environmental indicators are increasingly seen as necessary tools for helping to chart and track the course towards future." (Environmental …, 1997) Well-developed indicators allow evaluation of environmental impacts and to stimulate the development of more friendly farming practices (Environmental …, 1997; Sustainable Water …, 1998; Environmental Indicators …, 1999; Measuring …, 1999; Our Common …, 1987).

The objective of this research was to estimate the impact of farming practice on N leaching losses using indicator data obtained from small agricultural catchments. Subtasks of research were: to collect possible indicators of farming practice and to develop a simple



Source: figure made based on monitoring data of the Department of Environmental Engineering and Water Management, LLU

Fig. 1. Water discharge in small catchments in 1995-2003.

coefficients model for estimation of N leaching. The paper presents the indicators of risk of water contamination with nitrogen and the nitrogen leaching in small catchments, as well as correlation between nitrogen leaching and share of arable land, and a simple coefficients model to estimate N leaching.

Materials and methods

Climate

Latvia is situated in a region of humid and moderately mild climate. Average precipitation in Latvia varies from 550 to 700 mm, evaporation – 450 mm. Excess water causes runoff which averages from 200 mm to more than 300 mm. Maximum and minimum extremes in water discharges by the years 1995-2003 are shown in Fig. 1.

Maximum river discharges are usually observed during spring flood events. In Latvia about 50% of the annual runoff is generated from snowmelt in spring, 30% from rainfall events, and only 20% from groundwater discharges during low flow periods.

Description of the monitoring sites (catchments)

Agriculture is the main source of the river runoff pollution contributing nitrogen load to the Gulf of Riga and the Baltic Sea. The inland water bodies receive nitrogen from two types of agricultural pollution sources – point and diffuse sources. In an assessment

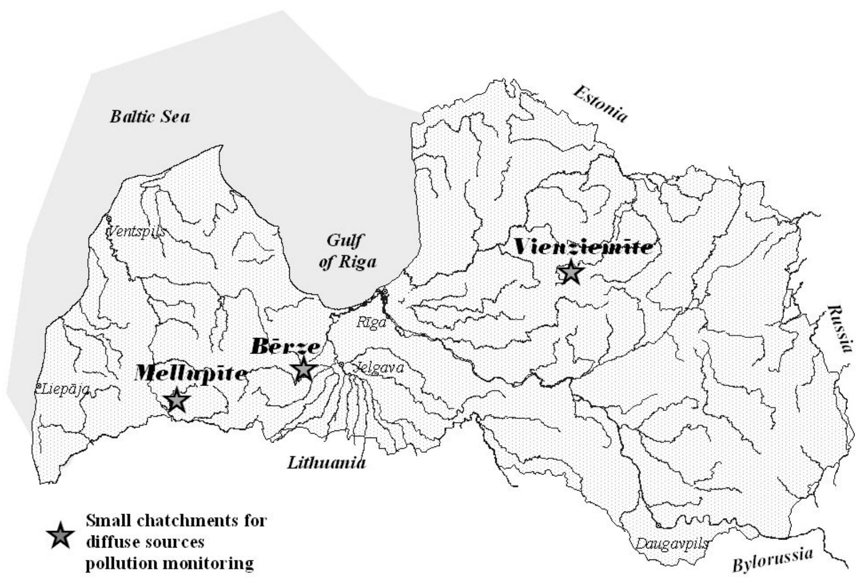


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Fig. 2. Agriculture diffuse monitoring sites in Latvia.

of diffuse pollution, it is important to control nutrient balances excluding point source pollution – large animal farms and wastewater from households. Therefore, three small monitoring catchments of diffuse source pollution (Berze, Mellupite, and Vienziemite) have been established in Latvia (Jansons, 1998). They are located in different parts of Latvia (Fig. 2).

Drainage description

Diffuse source monitoring sites in Latvia represent different climatic and physical conditions and farming systems. Sandy loam soil and low-input farming are dominant in the Vienziemite catchment, moderately intensive farming with loam soil are dominant in the Mellupite catchment, but in the Berze catchment silty clay soil and intensive farming are dominant (Table 1). The landscapes in catchments vary from hills in Vienziemite to plains in the Berze catchment.

The application of the amount of fertilizer per ha depends on intensity of farming and knowledge of farmers. In a catchment with less favorable conditions for agriculture – Vienziemite the average amount of fertilizers applied per year on average makes approximately 4 to 5 kg ha^{-1} of N), while in a catchment with very favorable conditions for agriculture – Berze – the average amount of fertilizers applied on fields is 15 to 90 kg ha^{-1} of N.

Field scale drainage systems are located within the catchment (Vienziemite) or border directly with the main catchment area (Berze, Mellupite). The Berze and Mellupite fields are only agricultural land, but the Vienziemite drainage collects also runoff from a small forest area.

The runoff measurements and water sampling were carried out in small streams or drainage field outlets of the small catchment areas at two levels – field and catchment. Measurements in the catchments were based on fixed measurement structures, i.e. crump (Mellupite), V-shape (Berze) and combined profile weirs (Vienziemite) equipment with automatic data loggers and sampling equipment for continuous water level registration and automatic composite water sampling (only in the Mellupite catchment). Collection of composite water samples was 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 were started in the Berze and Vienziemite catchments in 1994 and in the Mellupite catchment in 1995.

Water analyses were carried out in Latvia according to standard methods. The Latvian laboratory achieved satisfactory precision against a Norwegian laboratory (Jordforsk) in intercalibration tests. The parameters analyzed included total N, NO_3-N, NH_4-N, total P, PO_4-P, pH, Ca, Na, Mg, and K.

Application of indicators for assessment of water quality

Excessive nutrients can result in excessive growth of phytoplankton and potentially harmful algal blooms leading to oxygen declines, human and animal health threats and a general decline in the water quality. The most relevant cause of eutrophication is the loading of nutrients, particularly nitrogen and phosphorus, from different sources (Cardoso et al., 2001). Moreover, total nitrogen and total phosphorus are often good predicators of algal blooms in inland waters. The most important environmental directive concerning nutrients from agriculture and dealing with pollution caused by

Table 1

Description of agricultural diffuse monitoring sites

Site, level of monitoring	Area, ha (% of agricultural land)	Soil	Intensity of agriculture
Vienziemite Drainage field	592 (78) 67 (85)	Sandy loam	Low-input farming, arable crops 4-5% within catchment Low-input farming, small plots of arable crops in drainage field
Mellupite Drainage field	960 (69) 12 (100)	Loam, clay loam	Moderately intensive farming representing average situation, arable crops 35-45% within catchment Cereals in drainage field
Berze Drainage field	368 (98) 77 (100)	Silty clay, loam	Intensive grain farming, arable crops 80-90% within catchment Cereals in drainage field

Note: data of field trials performed by the Department ofEnvironmental Engineering and Water Management, LLU

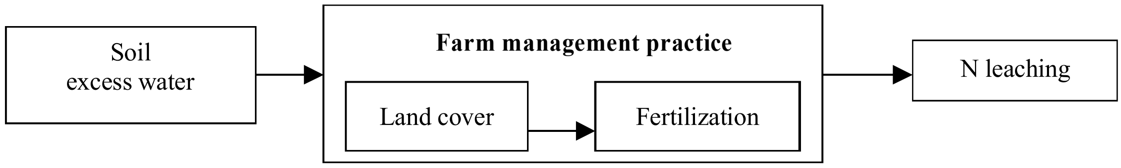

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Fig. 3. Relationship between N losses and farm management practice.

nitrates from agricultural sources is the Nitrate Directive (91/676/EEC).

Indicators allow measuring and assessing the trends of farming impact on environment. There are many indicators or many measures needed for assessment of farming practice on water quality. These indicators are useful to establish a clearer link between agriculture production, farm management practices, and water pollution.

A core set of indicators that build on the information based on currently available farm management data are collected over time (Fig. 3).

The indicators used in the assessment of farm management are selected from OECD recommendations (OECD, 1997), but are restricted to those that have been collected regularly by the annual inventory of farms in monitoring catchments. A short list of the possible indicators of sustainable farming includes the following:

– acreage of the agricultural land;
– acreage of the arable crops;
– application of mineral and organic fertilizers.

Monitoring program in small catchments requires very specific equipment and has high costs. Therefore, only small part of agricultural land is covered by monitoring in Latvia. Another possible estimation of nutrient load could be based on empirical calculation models relating nitrogen loss to land use, soil types, climate, fertilization application, etc. Land use and fertilizer application are the major management indicators (Jansons et al., 2003).

The Mellupite and Berze catchments at field level have mainly arable land. On this basis, estimation of losses of nitrogen from arable land can be predicted as a function of water discharge and N balance (1):

$$N_{losses,kg/ha} = \frac{B(Q+W)\cdot X}{Q}\ , \qquad (1)$$

where: B – nitrogen balance per ha;
Q – water discharge, mm;
W – soil capacity to store water, mm;
X – coefficient of modeling.

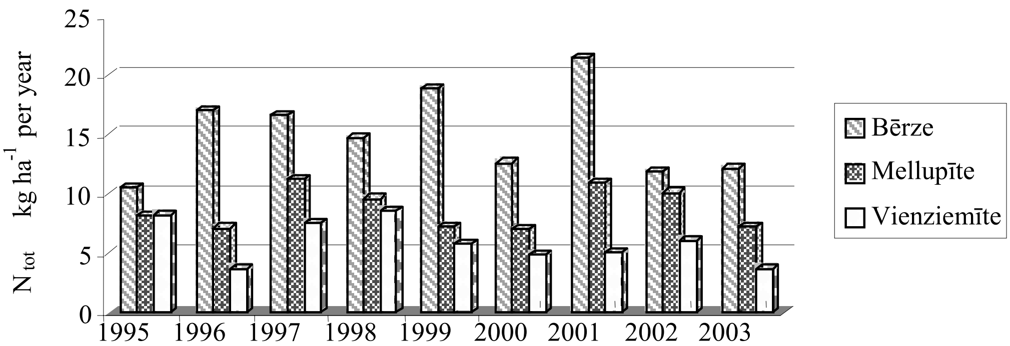
Nitrogen leaching estimation from the whole catchment (farms) is a function of nitrogen losses from arable land and the rest of farm area (2):

$$N_{losses} = N_{arable} + N_{rest}. \qquad (2)$$

Nitrogen leaching from the rest of the areas (grassland, meadows, forests, etc.) has been calculated as a function of water discharge.

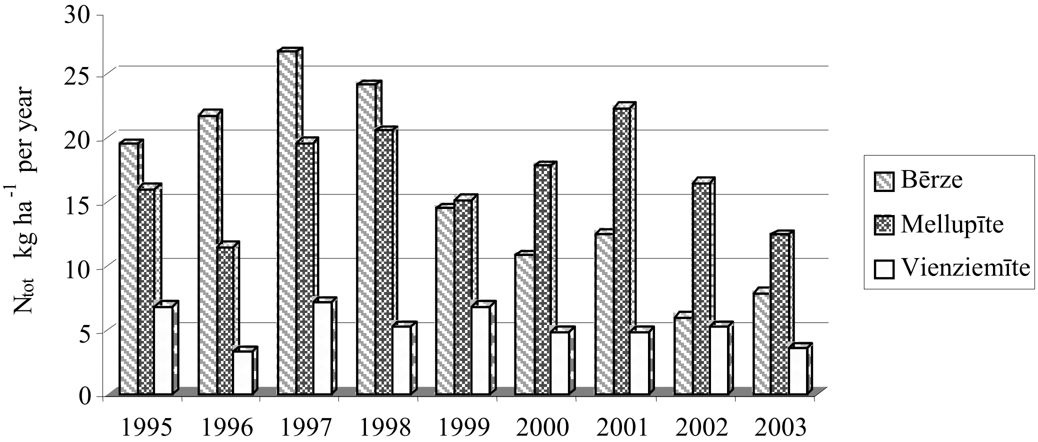
Results

Nitrogen loss for the three catchments is shown in Figure 4. The greatest N runoff occurred in connection with the spring flood, and the lowest was observed during the summer period. The lowest N losses were observed in Vienziemite, where share of arable land is



Source: based on monitoring data of the Department of Environmental Engineering and Water Management, LLU

Fig. 4. Nitrogen loss from catchments in 1995-2003.



Source: figure made based on monitoring data of the Department of Environmental Engineering and Water Management, LLU

Fig. 5. Nitrogen loss from drainage fields in 1995-2003.

comparatively low – 4 to 5% and which is dominated by subsistence farming. The Mellupite site represents a moderate Latvian agriculture situation. N losses from the Mellupite catchment are higher than in Vienziemite and occur from 7 to 11 kg ha^{-1} of N per year). In the Berze catchment with intensive agriculture, N losses range from 10 to 19 kg ha^{-1} of N per year).

Nitrogen losses in drainage fields are shown in Figure 5. The lowest N losses (3 to 7 kg ha^{-1} of N per year) were observed in Vienziemite, where the share of arable land is low – at about 2 hectares and the catchment is dominated by grassland. N losses from the Mellupite drainage field are higher than in Vienziemite and occur from 12 to 23 kg ha^{-1} of N per year. In Berze drainage field with intensive agriculture, N losses range from 6 to 27 kg ha^{-1} of N per year.

Discussion

Using the above equation, nitrogen losses from arable land have been calculated and tested for the Mellupite and Berze catchment drainage fields, where arable land is 100%. The model coefficient could be estimated as (3):

$$X = 0.0489\ln(Q) - 0.2051, \qquad (3)$$

where Q = water discharge.

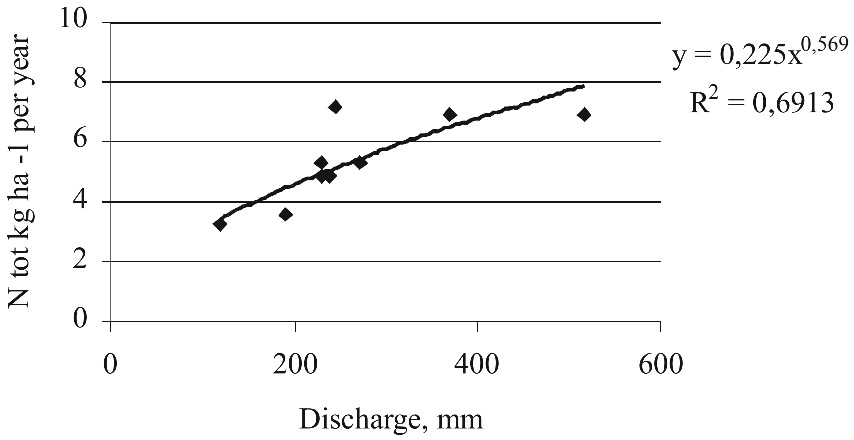
Errors between measured and calculated nitrogen losses vary from 6 to 27% in Mellupite drainage field, and from 8 to 36% in Berze drainage field, except for one year in Berze drainage field where the error was 79% (Table 2). Errors depend on how reliable data source is. One common cause of error is the problem of reliable farm data (yields and fertilization). A distinc-

Table 2

Measured and calculated N losses from arable land (drainage fields)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	Average in 1995-2003
Mellupīte										
Measured, kg ha^{-1}	16.1	11.5	19.7	20.6	15.2	17.9	22.4	16.5	12.4	16.92
Calculated, kg ha^{-1}	18.7	14.6	18.1	19.3	16.5	15.8	17.7	18.3	13.1	16.89
Error, %	16	27	-8	-6	8	-12	-21	11	6	- 0.2
Error, kg ha^{-1}	2.6	3.1	-1.6	-1.3	1.3	-2.1	-4.7	1.8	0.7	-0.06
Bērze										
Measured, kg ha^{-1}	19.6	21.8	26.8	24.2	14.6	10.8	12.5	6.0	–	17.04
Calculated, kg ha^{-1}	16.4	13.9	18.7	20.4	15.7	13.8	15.8	10.8	–	15.70
Error, %	-16	-36	-30	-16	8	28	27	79	–	- 7.8
Error, kg ha^{-1}	-3.2	-7.9	-8.1	-3.8	1.1	3.0	3.3	4.8	–	-1.33

Note: the authors’ calculations based on monitoring data



Note: figure made based on the authors' calculations

Fig. 6. Relationship between N_{tot} losses and drainage field discharge.

tion should be made between water quality data from Berze and Mellupite. In Mellupite station flow proportional sampling equipment is more advanced than in Berze, where random (grab) water sampling is used. However, errors could reflect the natural variation in water quality in both spatial and temporal terms, e.g. in yearly variation of climate.

The study results show that N losses from monitoring sites are influenced by farming practice, share of arable land, and annual water discharge. The percentage of land use for agriculture and acreage of the arable land are important factors in explaining variations in N_{tot} loads in monitoring sites (Jansons et al., 2003). The data indicate that N losses from monitoring sites are influenced by nitrogen surplus in soil after the harvest. The results show that N loading per ha of agriculture land increased with the increase of N surplus in the N balance.

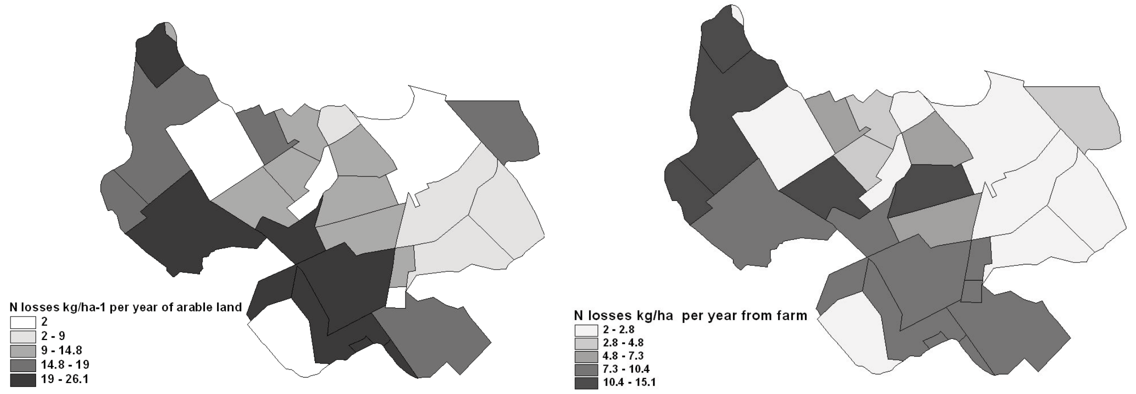
Nitrogen leakage calculation (N rest) from other land use types (abandoned agricultural land, meadows for

Table 3

Measured and calculated N losses in catchments

	1995	1996	1997	1998	1999	2000	2001	2002	2003
Bērze									
Arable land	20.0	17.9	19.2	20.4	18.4	16.3	18.9	18.0	12.0
Rest	4.6	4.2	4.4	4.6	4.5	3.6	5.0	4.4	3.5
From catchment, calculated	4 776.8	5 066.8	5 723.3	5 981.9	4 954.4	4 292.9	5 860.2	4 818.6	
measured	3 867.7	6 267.0	6 094.1	5 420.6	6 955.2	4 629.4	7 875.2	4 386.6	
error, %	24	-19	-6	10	-29	-7	-26	10	
Mellupīte									
Arable land	17.5	16.1	25.5	22.1	25.3	21.1	32.5	17.3	14.1
Rest	5.8	4.3	5.3	6.1	6.1	3.9	5.1	5.6	3.6
from catchment, calculated	8 351.3	6 746.8	1 1006.7	1 1291.5	9 650.0	8 530.1	1 252.8	9 474.4	7 166.5
measured	7 737.6	6 806.4	1 0713.6	9 177.6	7 968.0	6 739.2	1 046.4	9 705.6	6 931.2
error, %	8	-1	3	23	21	27	20	-2	3
Vienziemīte									
Arable land	19.8	12.5	17.8	16.7	16.8	16.5	15.9	18.5	15.3
Rest	7.4	3.5	5.9	7.0	4.8	6.0	5.5	5.6	4.7
from catchment, calculated	4 744.0	2 285.4	3 758.3	4 391.5	3 168.6	3 764.6	3 433.3	3 572.3	2 941.8
measured	4 854.4	2 190.4	4 440.0	5 097.1	3 445.4	2 924.5	2 983.7	3 557.9	2 368.0
error, %	-2	4	-15	-14	-8	29	15	0.4	24

Note: the authors' calculations based on monitoring data



Note: figure made based on the authors' calculations

Fig. 7. N losses kg ha^{-1} per year of arable land and kg from the farm.

hay and pastures with small forest area) would have to be based on data from the Vienziemite drainage field (67 ha). Vienziemite drainage field during the years 1994-2003 has few small plots of arable crops without fertilization and minor forest area (15%). The correlation between N losses and nutrient balance is low in Vienziemite, since the share of arable land is very low and farming practice is of low input.

The drainage field measurements in Vienziemite show that the correlation between annual water discharges and nitrogen losses is high (Fig. 6).

Nitrogen losses from the rest of the territory correspondingly can be estimated as:

$$N_{rest} = 0.225 \cdot Q^{0.569}. \qquad (4)$$

Nitrogen losses from the whole catchment have been calculated as sum of nitrogen losses from arable land and the rest of the territory. Data shows that difference between calculated data and measured data varies from 0.4 to 29% (Table 3).

The reasons for errors could be that a simple model is used to estimate a comprehensive relationship between farming practice and nitrogen leaching. Due to simplification, the model does not present exact values of leaching. The model leaves out the influence of retention, slope, actual crop, soil tillage, etc. – factors which impact nitrogen leaching.

Identification of critical areas and of too intensive farming practice has a significant role in water pollution management in Latvia. The catchment approach can be used in farms. In this study, spatial distribution of N leaching combination with GIS-media within Mellupite catchment is used to estimate approximate nitrogen leaching from the farms.

The study shows that nitrogen leaching in the Mellupite catchment farms ranges from 6 to 30 kg ha^{-1} of N per year of arable land (Fig. 7). The total area of arable land in the Mellupite catchment in the year 2003 is 353.3 ha, but the average loss of nitrogen from a hectare of arable land in the catchment is 17 kg.

Total nitrogen losses from farms are subordinated by area of arable land in farms. Study data shows that nitrogen losses on farms with a smaller size of arable land are lower in the Mellupite catchment. Average N losses from the farm range from 7 to 10 kg ha^{-1}.

Conclusions

1. Diffuse agriculture pollution varies widely and is a complex function of land use, agronomic, edaphic and climatic factors.
2. Sustainable agriculture depends on farm sustainability, and simple indicators based on easy collection and calculation is an important tool in the assessment of farm management practice within farm sustainability.
3. Based on research data, nitrogen losses from of arable land are influenced by farming practice – nitrogen balance in farms. Research data shows that nitrogen losses in Berze and Vienziemite catchments range from 12 to 20 kg ha^{-1} of N per year of arable land, but in Mellupite – from 14 to 32 kg ha^{-1} of N per year of arable land.
4. Based on research data, nitrogen losses from farmland can be reduced by proper farming practice – based on the nitrogen balance in farms and an acceptable share of arable land on a farm.

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Anotācija

Gandrīz visi pasaules resursi tiek izmantoti lauksaimniecībā. Pieaugot lauksaimniecības intensifikācijai, rodas slodze uz vidi un pārmērīgs dabas resursu patēriņš, tāpēc dabas resursu monitorings un videi draudzīga saimniekošana ir svarīgs vides politikas mērķis Latvijā. Līdzsvaru starp lauksaimniecisko darbību un vidi nodrošinās ilgtspējīga lauksaimniecība. Zemnieku saimniecības ilgtspējības izvērtēšanai ir nepieciešami labi izstrādāti indikatori un to apkopošanas un izmantošanas metodika. Lauksaimniecība ir viens no galvenajiem slāpekļa savienojumu izneses avotiem, kas izraisa ūdeņu eitrofikācijas un piesārņošanas problēmas. Mūsu pētījumu rezultāti rāda, ka saimniecības slāpekļa bilance un aramzemes platība būtiski ietekmē slāpekļa noplūdi.