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Nitrogen leaching from grassland in Lithuania

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dedicated to our Estonian colleague Enn Gutmann who died too early

Abstract

Leaching losses from the soil contribute to undesired nutrients loads into surface water. It was the aim of the presented paper to give an overview of nitrogen (N) leaching losses from long-term drained cultivated grassland in relation to land use in Lithuania. In comparison with mown grassland (MG), the soil bulk density decreased between 2 and 9 % in set-aside grassland (SAG) within a 6-year period of investigation. Mineralization of the grass residues in spring increased the nitrate nitrogen (NO_3-N) content 1.5 - 2.0-fold in the SAG compared with the MG treatment. Correspondingly, the NO_3-N concentration in the drainage flow was 1.5 times higher. The mean annual NO_3-N and total nitrogen (N_{tot}) leaching losses from the MG plots were 1.7 ± 0.9 and 7.9 ± 3.0 kg $ha^{-1}yr^{-1}$, respectively. In comparison, the leaching losses from SAG that was not fertilized were 4.0 ± 1.5 NO_3-N kg $ha^{-1}yr^{-1}$ and 11.6 ± 3.2 kg N_{tot} $ha^{-1}yr^{-1}$. Fertilization of MG with 60 kg N ha^{-1} had no significant influence on the NO_3-N content in the soil and drainage flow.

Ploughing the grassland (PG) and sowing of spring cereals increased the NO_3-N content in the soil by 15 to 40 mg kg^{-1}, but losses decreased after two years to values of 5 to 11 mg kg^{-1}. The NO_3-N and N_{tot} concentration in the drainage flow increased by 3.5 - 6.1 and 6.2 - 9.1 mg L^{-1}, respectively. Leaching losses were 12.4 kg NO_3-N ha^{-1} yr^{-1} and 20.0 kg N_{tot} $ha^{-1}yr^{-1}$. After two years, the leaching losses varied only slightly between 2.0 and 5.0 kg N_{tot} $ha^{-1}yr^{-1}$.

Key words: grassland, drainage flow, leaching, nitrogen, nitrate

Zusammenfassung

Stickstoffauswaschung auf Grünlandflächen in Litauen

Auswaschungsverluste aus Böden tragen zu unerwünschten Nährstoffeinträgen in Oberflächengewässern bei. Ziel des vorliegenden Beitrages war es, einen Überblick über Stickstoff-(N)-Auswaschungsverluste auf drainierten Dauergrünlandflächen in Abhängigkeit von der Nutzungsform in Litauen zu geben. Im Vergleich zu Grünland, das gemäht wurde (MG), führte die Stilllegung (SAG) innerhalb eines Beobachtungszeitraumes von 6 Jahren zu einer Abnahme der Lagerungsdichte um 2 bis 9 %. Die Mineralisierung der Grasrückstände im Frühjahr erhöhte den Nitratgehalt in der SAG-Variante im Vergleich zur MG-Variante 1,5 bis 2-fach. Dementsprechend wurde ein Nitratgehalt im Drainagewasser, der 1,5 Mal höher war, bestimmt. Die durchschnittlichen jährlichen Auswaschungsverluste betrugen 1,7 ± 0,9 kg NO_3-N ha^{-1} a^{-1} und 7,9 ± 3,0 kg N_{tot} $ha^{-1}a^{-1}$ auf den MG-Parzellen. Auf den Stilllegungsflächen wurden entsprechende Werte von 4,0 ± 1,5 kg NO_3-N ha^{-1} a^{-1} und 11,6 ± 3.2 kg N_{tot} $ha^{-1}a^{-1}$ bestimmt. Eine Stickstoffdüngung in Höhe von 60 kg $ha^{-1}a^{-1}$ führte auf den MG-Parzellen zu keiner signifikanten Zunahme des NO_3-N-Gehaltes im Boden und im Drainagewasser. Das Pflügen des Grünlandes (PG) mit anschließender Saat von Sommergetreide erhöhte den NO_3-N-Gehalt im Boden um 15 - 40 mg kg^{-1}, wobei dieser Anstieg nach zwei Jahren nur noch 5 - 11 mg kg^{-1} betrug. Der NO_3-N und N_{tot}-Gehalt im Drainagewasser stieg um 3,5 - 6,1 bzw. 6,2 - 9,1 mg L^{-1}. Die Auswaschungsverluste betrugen in dieser Behandlung im Mittel 12,4 kg NO_3-N $ha^{-1}a^{-1}$ und 20,0 kg N_{tot} $ha^{-1}a^{-1}$. Nach zwei Jahren lagen die Auswaschungsverluste für N_{tot} nur noch bei 2,0 bis 5,0 kg $ha^{-1}a^{-1}$.

Schlüsselworte: Grünland, Drainagefluss, Auswaschung, Stickstoff, Nitrat

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1 Introduction

The agricultural reform and restoration of private ownership of land in the course of the restoration of the independence in Lithuania in 1991 dramatically changed the structure of crop and land use. After a sharp increase of prices for fertilizers, the area of land used for agricultural production decreased by > $500 \cdot 10^3$ ha since 1990 including $250 \cdot 10^3$ ha of perennial pastures and meadows. Such meadows, however, provide favourable conditions for the growth of natural vegetation and mineralization of organic residues (Motuzas et al., 1996, Vozbuckaja, 1964). Some of the land comprised drained cultivated pastures and meadows.

The steep increase of prices for fertilizers yielded a restricted use of N and the mean application is actually about 40 to 50 kg N ha^{-1}.

Such drastic changes in land use occurred in many countries in transition and similar alterations can be expected in countries where farms are still owned by the state. It is generally acknowledged (Helsinki Commission, 1996) that the decrease in agricultural production and fertilizer use improved the surface water quality. However, there is little information on the leaching of nutrients when land use changes fast and widely (Meissner et al., 1998, Lofgren et al., 1999, Jansons et al., 2002). Another problem of controlled experiments is that high rates of manure and fertilizers were applied, while other aspects such as soil cultivation, crop type and crop rotation were neglected (Rekolainen et al., 1991, Addiscott et al.,1997, Torstensson, 1998, Jaynes et al., 2001). It is, however, important to identify those parameters, which enhance the risk of N leaching losses in both, extensive and intensive farming systems.

The phosphate (PO_4-P) and ammonium nitrogen (NH_4-N) load into the upper courses of rivers in Lithuania, where are no big cities and industry not being contributing to the nutrient input, showed a decrease of PO_4-P and NH_4-N concentrations by factor 1.8 and 5.8 from 1990 to 2002 (Sileika, 2000). During the same time the NO_3-N concentration increased by factor 3.6. Though the NO_3-N concentration and N load into rivers is not alarming, the reasons need to be found for predicting future developments.

Stalnacke (1996) found no decrease of nitrate (NO_3) concentrations from 1987 to 1995 in the 12 major Latvian rivers. Similar results were obtained by Keeney and DeLuca (1993) for the Des Moines river during the period 1945 – 1980.

The type of crop plant and soil properties influence the variation of N compounds in the soil (Johnson, 1990; Ezerinskas, 1998; Aksomaitiene and Kutra, 2000; Trepel and Reiche, 2000). Using GIS modelling methods N leaching losses increased linearly with the N input on pastures and N leaching losses from fallow land were about 3 - 4 times higher than those from grassland (Trepel et al., 2000). N leaching losses from perennial grassland were about 1.5 - 2.5 times lower than from crop rotation fields (Aksomaitiene and Kutra, 2000). Grazed grassland can be a major source of NO_3 pollution of surface waters if live-

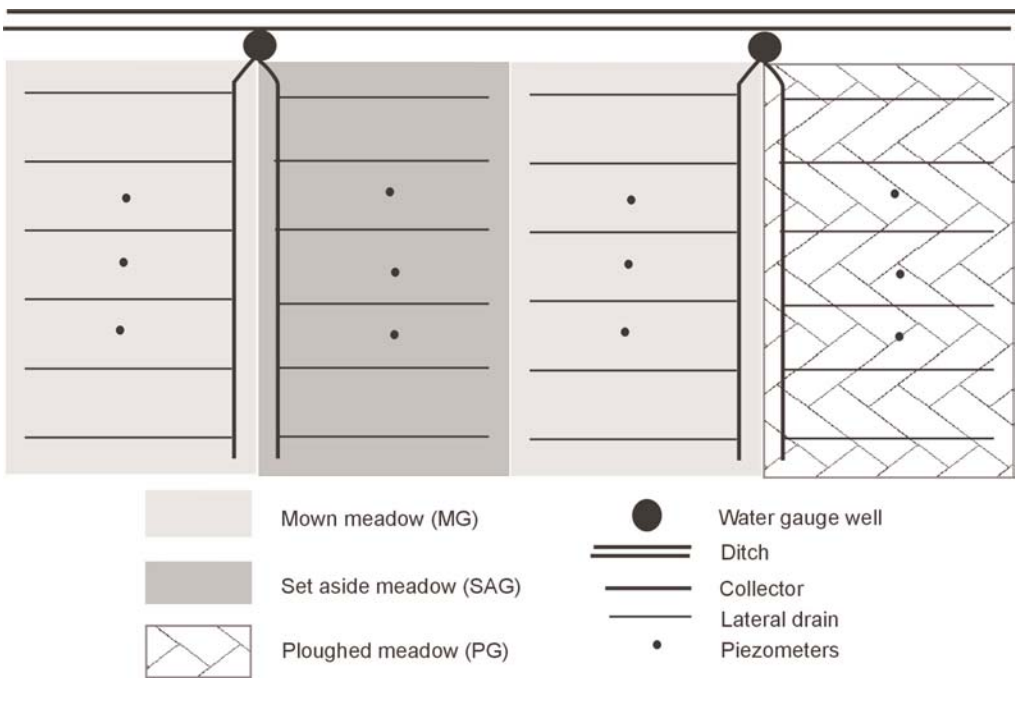

Fig. 1:
Experimental design of the field experiment

stock graze on land adjacent to watercourses. Heathwaite et al. (1990) showed that the total nitrogen load in surface waters runoff from heavily grazed permanent grassland was nine times higher than that of lightly grazed grassland. Most of the N was lost in the form of NH_4-N.

Still little data exists about nutrient leaching losses from drained set aside and ploughed grassland in extensive farming systems in Lithuania. The paper presents the results of a comparative study with view to the variation of N compounds in the soil, N concentrations in drainage flow and N leaching losses from mowed, set aside and ploughed grassland that was managed according to the guidelines of best agricultural practice.

2 Materials and methods

The study was carried out in the valley of the river Nevezis in the Lithuanian Middle Plain (55°25'N, 24°05'E). Four experimental plots of 0.95 ha size were established within a long-term (>10 years) cultivated grassland field on a drained alluvial peat soil. Individual drainage systems with drainage water collection wells were installed in each plot (Fig. 1).

Six tile drainage pipes at distances of 28 meters were laid at a depth of 0.8 - 1.0 m in each experimental plot. Three different grassland management systems were studied from 1996 to 2002:

1. set aside grassland ('SAG'),
2. mown grassland ('MG'),
3. spring barley after ploughing the grassland ('PG').

Grass was sown in 1984. Until 1996 the grass was mown 2 - 3 times per year. Fertilizers were annually applied at rates of 60 kg N ha^{-1} yr^{-1}, 50 kg P ha^{-1} yr^{-1} and 50 kg K ha^{-1} yr^{-1}.

The SAG grassland was not mown and not fertilized since 1997. The MG was not fertilized in the period from 1997 to 1999. In 2000, the MG field was fertilized 60 kg N ha^{-1} yr^{-1}. Grass was mown twice a year. The mean grass yield was 6.1 - 10.2 t ha^{-1} dry matter.

The PG plots were ploughed in October 1996 and barley was sown in spring 1997. Hereafter, spring rape and barley were cultivated in rotation every year. The plots were ploughed in October and cultivated in the next spring every year until 2001. Barley received a fertilizer dressing of 60 kg N ha^{-1} yr^{-1}, 30 kg P ha^{-1} yr^{-1} and 30 kg K ha^{-1} yr^{-1}. Spring rape was not fertilized. The mean yield of barley was 2.0 - 3.0 t ha^{-1} and that of oilseed rape 1.8 - 2.0 t ha^{-1}, respectively. In 2001, the plots were ploughed in August after harvesting the oilseed rape and bare fallow was left in 2002.

3 Soil analysis

Soil bulk density and water conductivity were determined at the beginning and the end of the investigation. The water conductivity was determined by employing the infiltration method (Oosterbaan et al., 1994). The A-L method (GOST 26208-91, 1991, Samoschvalov et al., 1989) was used to determine the plant available phosphorus (P_2O_5) and potassium (K_2O) content in the soil. NO_3-N and NH_4-N were determined by an extraction method (ISO/CD 14256-2). The humus content was calculated on the basis of the results from dry combustion (Ministry of Environment, 1994).

The soil of the experimental site is an alluvial peat bog (Table 1). Loams of various particle size dominate in the alluvial sediment. The mean value for the water conductivity is 0.2 - 7.0 m d^{-1}. At the beginning of the study the soil contained 40 - 60 kg mineral N ha^{-1} in the 0 - 40 cm soil layer.

All flows leaving the plots were measured and water samples were taken at the points where the flows entered the water gauge well. The water flow was determined volumetrically every 1 - 3 days. The ground water level of each drainage system was measured every 2 - 5 days in the piezometers. Water samples from water gauge wells and piezometers were taken 8 - 12 times per year for determining the concentration of N_{tot}, NO_3-N and NH_4-N.

The N runoff was calculated by using a linear interpolation method (Helsinki Commission, 1994). For the statistical analysis a LSD test was performed in order to verify differences between treatments (Helsel, 1995).

Table 1:
Soil characteristics of the test site at the beginning of the experimentation

Soil layer	Ash content	Particles <0.01 mm	Soil density	Density of solid phase	Porosity	NO_3-N	P_2O_5	K_2O	Humus
(cm)	(%)	(%)	(g cm^{-3})	(g cm^{-3})	(%)	(µg g^{-1})	(µg g^{-1})	(µg g^{-1})	(%)
0-20	79-85	37-39	0.6-0.9	2.3-2.6	65-75	8-17	153-177	105-108	11-13
20-40	58-70	35-39	0.5-0.8	2.1-2.5	65-80	8-9	101-112	70-75	12-14
40-60	60-68	43-45	0.5-0.7	2.2-2.4	70-80	5-7	63-79	55-65	17-18
60-80	71-80	26-40	0.5-0.7	2.1-2.4	70-85	3-4	53-58	50-60	16-19

4 Results

The meteorological conditions varied largely between years. In 1996 and 2002, extreme drought and in 1998 extreme wetness prevailed. In all other years, the annual rainfall was close to the long-term average of 626 mm. The coolest year was 1996 (0.8 °C below the long-term average), while the warmest were 1999 and 2000 (1.7 and 2.0 °C above the long-term average).

The ground water level was similar in all plots during experimentation (Table 2). In 1997, when the grass was no longer mown, the mean annual run-off from the SAG plot was 30 % higher than on the MG plot.

Before the start of the experiment in 1996, the soil bulk density varied only little (Fig. 2). When the grass was no longer mown, the decaying grass mass obviously accumulated on the ground surface (3 - 4 t ha^{-1} dry matter yr^{-1}) and mineralization finally increased the organic matter content of the soil. Such tendency was noticed from 1997 to 2002. In the 0 - 40 cm soil layer, the organic matter content increased by 1.8 % in the SAG plots, while in the MG plots the increase was only 0.3 %. This further resulted in a reduced bulk density of 2 - 10 % in the 0 - 10 cm soil layer due to a reduced soil compaction induced by mowers and accumulation of organic matter (Juskauskas, 1997). Though there was a trend towards decreasing bulk

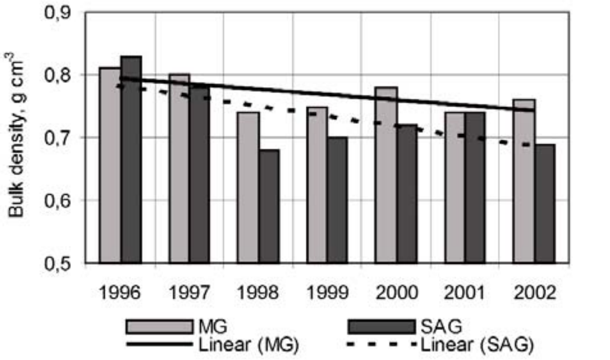

Fig. 2.:
Influence of the grassland management system on the soil bulk density of the 0 – 10 cm soil layer in MG and SAG plots during time course (1996 – 2002)

Table 2:
Hydrological characteristics of the experimental plots

Treatment	1996	1997	1998	1999	2000	2001	2002	1997-2002
Average ground water level (cm)								
MG	67	68	60	69	53	70	91	69 ± 31
SAG	72	74	64	61	56	77	95	71 ± 30
PG	72	71	52	52	60	82	96	70 ± 30
Annual runoff (mm)								
MG	183	245	269	230	269	117	165	216 ± 62
SAG	181	275	363	327	320	182	233	283 ± 67
PG	188	269	225	220	219	135	118	198 ± 58

Table 3:
Influence of the grassland management system on the NO_3-N (mg kg^{-1}) content of the soil during time course

	1996	1997-1999		2000-2002		1997-2002	
Treatment	October	May	October	May	October	May	October
0-20 cm							
MG	1.3	4.3a	1.7a	2.7a	5.7	3.5 ± 3.0a	4.1 ± 3.0
SAG	0.7	8.1	1.5	4.4	8.2	6.2 ± 6.1a	5.5 ± 5.1
PG	2.6	18.9b	6.5b	20.0b	18.9	19.7 ± 13.0b	14.0 ± 13.0
$LSD_{5\%}$		13.7	3.7	16.6	20.6	7.9	11.7
20-40 cm							
MG	1.4	5.0	1.3	3.9a	9.2	4.5 ± 2.6a	6.0 ± 7.4a
SAG	0.7	7.1	1.6	6.3	8.8	6.7 ± 3.1a	5.9 ± 5.9a
PG	2.9	19.9	24.6	13.3b	24.1	16.6 ± 9.9b	24.4 ± 16.b1
$LSD_{5\%}$		16.7	34.9	3.5	18.2	6.5	10.6

Different letters indicate statistically significant differences between treatments

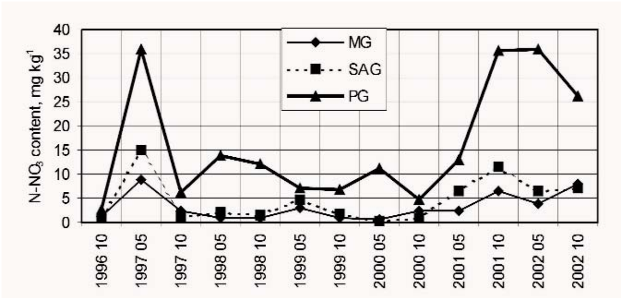

Fig. 3:
Influence of the grassland management system on the NO_3-N (mg kg^{-1}) concentration of soils (0 - 20 cm) during time course

densities in the SAG and MG treatments, differences proved to be not statistically significant.

A slight increase of the water conductivity was found in the SAG treatment, too. The mean infiltration rate in the MG and SAG treatments were similar in 1997 with 3.8 ± 1.9 m d^{-1} and 4.7 ± 0.8 m d^{-1}, while in 2002 there was obviously an increase in the SAG treatment, for which a value of 5.8 ± 1.5 m d^{-1} was determined.

Changes over time (1996 - 2002) in the NO_3-N content of the soil proved to be not significant (Table 3).

The decaying residues of set aside grass contributed besides the N fertilization at rates of 40 - 90 kg N ha^{-1} to the N supply of the plants. Correspondingly and compared to the MG treatment, which received no N fertilization up to this time, 1.9 and 1.4-fold higher NO_3-N concentrations were found in the 0 - 20 and 20 - 40 cm soil layer, respectively from 1997 to 1999. After supplying 60 kg N ha^{-1} to the MG plots in 2000, variations in the NO_3-N content between the SAG and MG treatment remained constant over time in both layers. The reason is most likely the increased grass yield after N fertilization.

It was striking that the variation of the N content was distinctly higher in the PG plots than in the MG and SAG treatments (Fig. 3).

After ploughing the PG plots in October 1996, the NO_3-N content in the soil increased almost by factor 14 (from 2.6 to 35.9 mg NO_3-N kg^{-1}) in May 1997. During the vegetation period in 1997 NO_3-N was partly taken up by plants and partly leached in deeper soil layers. This is reflected in the strongly increased NO_3-N content in the 20 - 40 cm soil layer in autumn of that year with 43.7 mg NO_3-N kg^{-1} compared and 6.2 mg NO_3-N kg^{-1} in the top soil. In spring 1998, the NO_3-N content was 2 - 3 times lower than in the previous fall samples, but still 2 to 5 times higher than in the MG plots.

In 2001, the cereal field plot was ploughed very early after the harvest of oilseed rape in August and remained as a bare fallow until 2002. Thus, a strongly increased NO_3-N content in the soil was found in fall and spring of the following year (Fig. 3). The NO_3-N content in both layers (0 - 20 and 20 - 40 cm) showed values of 36.0 and 17.0 mg NO_3-N kg^{-1} in spring and 16.4 and 27.2 mg NO_3-N kg^{-1} in autumn 2002. Differences between the MG and PG treatment proved to be significant.

The NH_4-N concentration varied between 0 and 5.0 mg NH_4-N kg^{-1} in the 0 - 20 cm soil layer, but differences between the treatments were not significant.

The influence of the management system of grassland on the concentration of different N compounds in the drainage flow is shown in Fig. 4.

The concentration of N_{tot}, NO_3-N and NH_4-N in the drainage flow was not significantly influenced by the management system in 1996. The concentration of N_{tot} varied only slightly in the MG and SAG plots during experimentation, while the NO_3-N concentration was higher in the SAG (1.3 mg L^{-1}) than in the MG (0.77 mg L^{-1}) treatment from 1997 to 1999. After fertilization of 60 kg ha^{-1} N in 2000 the NO_3-N concentration remained fairly constant in the MG plots.

After ploughing the grassland in October 1996, the NO_3-N concentrations increased within the next two years 3 to 5-fold with maximum values of 3.5 to 6.0 mg NO_3-N L^{-1}. The highest concentrations were found in the second year after ploughing. Hereafter, differences between MG, SAG and PG plots in the NO_3-N concentration of the drainage water decreased.

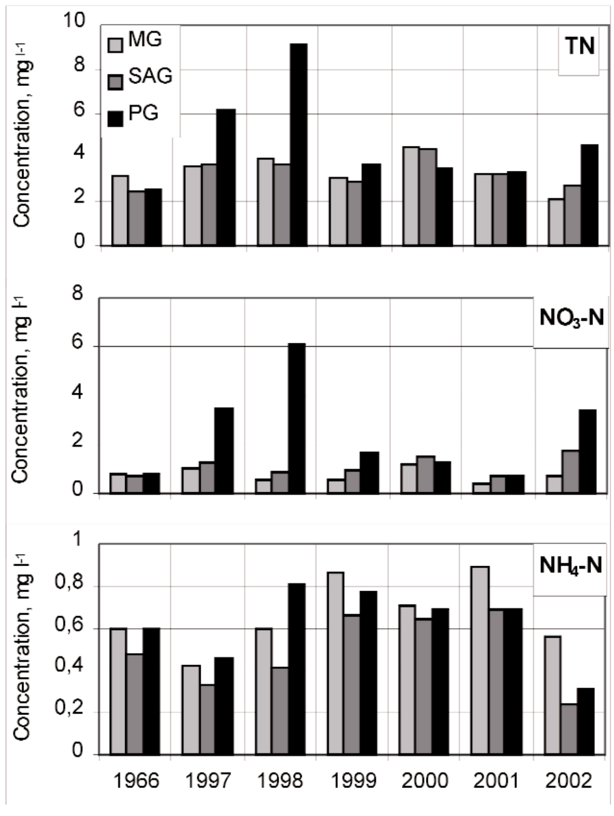

Fig. 4:
Influence of the grassland management system on the concentration of N compounds in the drainage flow during time course

Ploughing of the PG plot in August 2001 combined with fallow until spring 2002 increased the NO_3-N concentration to 3.5 mg NO_3-N L^{-1} in 2002. Differences in the mean NO_3-N concentration between the MG and PG treatment proved to be significant between years. Variations in the N_{tot} concentration were similar in all treatments, but differences were not significant.

Tendentiously the NH_4-N concentrations were lower in the drainage flow of the SAG plots than in the MG and PG plots, however, these differences were not significant.

The leaching losses of N compounds through drainage are directly related to their concentration and runoff volume (Helsinki Commission, 1994). At the beginning of the experiment the leaching losses of the investigated N compounds did not vary in relation to the management system (Table 4). Within time an increase in the NO_3-N losses from SAG plots was found and comparable with values determined for the MG plots. From 1997 to 1999 the NO_3-N losses from SAG plots were even higher than for the MG plots, which received no N fertilizer up to that time. The application of 60 kg ha^{-1} in the MG treatment had no influence on the NO_3-N losses that were determined afterwards.

Tendentiously, the NO_3-N leaching losses increased during time course in the SAG plots while those in the MG plots remained fairly constant. The NO_3-N losses were lowest on the MG plots when the hay yield was highest with 10.2 t ha^{-1} in 2001 as plants used water and N for the synthesis of biomass. A significant correlation was found between NO_3-N losses and hay yield ($Y = 0.03 \cdot X^2 - 0.9 \cdot X + 6.5$; r = 0.49 with X = NO_3-N loss (kg ha^{-1}) and Y = hay yield (t ha^{-1})). The NO_3-N leaching losses from the SAG plots where 1.5 times higher than from MG plots, but these differences were not significant.

Table 4:
Influence of the grassland management system on leaching losses of N (kg ha^{-1}) compounds during time course

Treatment	1996	1997-1999	2000-2002	1997-2002
TN				
MG	7.6	8.7a	7.1	7.9 ± 3.0a
SAG	6.2	12.0	11.3	11.6 ± 3.2b
PG	4.3	14.9b	8.0	11.4 ± 5.9b
$LSD_{5\,\%}$		4.9	5.1	3.4
NO_3-N				
MG	2.4	1.5a	2.0	1.7 ± 0.9a
SAG	1.9	3.7	4.4	4.0 ± 1.5
PG	1.4	9.1b	3.9	6.5 ± 4.7b
$LSD_{5\,\%}$		5.6	3.6	3.4
NH_4-N				
MG	1.1	1.6	1.0	1.3 ± 0.6
SAG	0.9	1.5	1.2	1.3 ± 0.8
PG	0.7	1.7	0.8	1.3 ± 0.6
$LSD_{5\,\%}$		0.6	0.8	0.4

Different letters indicates the significant differences between treatments

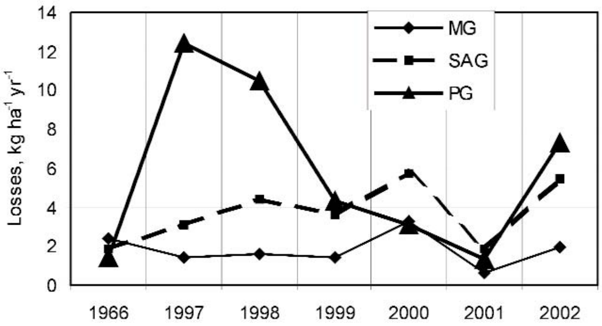

Fig. 5:
Influence of the grassland management system on NO_3-N leaching losses during time course

The highest N leaching losses were found on the PG plots during the first two years after ploughing the grassland and where six times higher than on the mown grassland. During the third year the N leaching losses decreased by factor 3 on the PG plots and were only slightly higher than on the MG plots (Fig. 5). In 2002, massive thawing resulted in increased losses of NO_3-N, particularly on the MG and SAG plots. The NH_4-N losses showed only minor differences among the treatments.

5 Discussion

The results of the presented experiment reveal that set aside grassland contributed best to an improved environmental quality in terms of N losses. On set aside grassland the soil accumulated more N than mown grassland so that the risk of N losses is lower. Additionally, soil compaction was reduced and the water runoff increased. The mean NO_3-N concentrations in the drainage flow was 1.16 ± 0.5 mg NO_3-N L^{-1} and leaching losses were about 4.0 ± 0.5 mg NO_3-N ha^{-1} yr^{-1}. Thus leaching losses equalled the NO_3-N load coming from rainfall (4 kg ha^{-1} yr^{-1} NO_3-N) (Sileika, 2000).

Leaching losses of NO_3-N on set aside grassland could be further reduced by de-installing drainage pipes (Parkinson, 1993). Many studies showed that the denitrification activity in soils is correlated with the water content (Vinten and Smith, 1993). Anaerobic, waterlogged conditions on undrained plots stimulate the denitrification of N compounds so that the NO_3-N concentration is much lower in the surface flow (Armstrong and Burd, 1993). Egginton and Smith (1986) found that the application of 500 mm water to grassland, that received a dose of 100 kg NO_3-N ha^{-1} resulted in a denitrification rate of > 2 kg ha^{-1} d^{-1}.

The lowest annual N_{tot} (7.9 ± 3.0 kg ha^{-1}) and NO_3-N (1.7 ± 0.9 kg ha^{-1}) leaching losses were found on MG plots. A fertilizer rate of 60 kg $ha^{-1}yr^{-1}$ did not increase the NO_3-N concentration in the drainage flow of the MG plots. Barraclough et al. (1983) found that NO_3-N leached from cut grassland, expressed as equivalent percentages of applied N (1.5, 5.4 and 16.7 %) increased correspondingly with higher N application rates of 250, 500 and 900 kg N ha^{-1} yr^{-1}. On ungrazed grassland, even if high N rates would be applied no substantial leaching of NO_3-N is to be expected if the fertilizer application matches the N demand of the grass crop. N leaching losses from grazed grassland were higher because the N off-take of animals by live weight and milk production is much lower than by the harvested grass.

Ploughing the grassland in autumn significantly increased the NO_3-N content in the soil and its concentration in the drainage flow during the first two years. The reason is the increased mineralization rate and accordingly increased amount of N, which is prone to be leached. The NO_3-N content in the topsoil increased up to 40 mg kg^{-1}, but after two years not more than 11 mg kg^{-1} were found. In the drainage flow the NO_3-N and N_{tot} concentration varied between 3.5 and 6.1, and 6.2 and 9.1 mg L^{-1}, respectively. In total, the NO_3-N and N_{tot} leaching losses accounted for 10.5 to 12.4 and 17.3 to 20 kg ha^{-1} yr^{-1}, respectively.

Changes in the land use after the agrarian reform came into force in Lithuania involved ploughing of permanent grassland since then, which consequently contributed to increased NO_3-N losses by leaching. This affected most likely also the quality of river water as increased NO_3-N levels were found in the territories of agricultural production. Cameron and Wild (1984) yielded similar results in the UK, a loss of 100 kg nitrogen over two years following autumn ploughing of a 3-year grass ley was measured, whereby a considerable part of the loss was due to leaching in the first winter, prior sowing the spring crop. MAFF (1993) calculated that between 100 and 200 kg N ha^{-1} is likely to be released after ploughing of three-year old ley and that this figure may even be higher for older grassland. This is an important factor to be considered when including ley in a crop rotation or when ploughing set aside grassland. An efficient counter-measure is a vegetated soil over winter, which can be achieved by sowing of winter cereals, inter-crops or a *Brassica* crop. In this context Gustafson (1995) found out that oilseed crops have by far the best ability to take up remaining mineral N that has been released during the autumn.

On light soils, which are most sensitive to leaching and if ley is to be followed by a spring cereal crop, the grassland should be ploughed relatively late in autumn in order to decrease the risk of N leaching as mineralization processes are restricted at low temperatures.

A comparison of N losses between extensive and intensive land use shows that losses from extensive land use, as described in this study, are typically an order of magnitude lower than from intensive land use, but processes and patterns of the main leaching factors are the same.

6 Conclusions

The continuously increasing area of drained grasslands that has been ploughed in some Lithuanian watersheds causes nutrient losses and contributes to the pollution of surface waters. Therefore different grassland management systems were tested with view to their ecological impact. The presented study revealed the influence of different grass management systems on N mineralization processes and hence the potential for N leaching losses. Different grass management systems left different amounts of N residues in the soil and increased the risk of N leaching losses in the order: mown grassland < set aside grassland < cereals < bare fallow.

Drained set aside grassland had a positive effect on physical soil properties such as water conductivity but it did not reduce NO_3-N leaching most efficiently. The lowest leaching losses were determined on regularly mown, moderately fertilized, ungrazed grassland.

Plant coverage during winter is the best way to limit N losses after ploughing. If there is no possibility to establish a winter cover crop, grassland should be ploughed in late autumn when mineralization of organic matter is only low, or shoulders of permanent ungrazed cut grassland should be established along sensitive water courses.

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