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Nitrate variation in drainage water under degradation of peat soils

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In 1997–2007, a research on the variation of nitrate concentration in peat soil drainage water and its dependence on annual precipitation, average air temperature, discharge and groundwater level were carried out. Tilling of mull fluvisol while cultivating cereals stimulated nitrate accumulation in the soil and leaching via drains. The average nitrate concentrations in meadow drainage water were 5.95 and in tillage land 16.94 mg · l^{-1}, those of the leakage being 8.5 and 26.2 kg · ha^{-1}, respectively. Nitrate concentration in the water of mineral soil, which had 5–7 times less organic materials compared with peat soil, was about 2.5 times lower. A stronger functional link was found between the content of nitrates in soil and water with drainage discharge and the groundwater level; a weaker link was observed with precipitation, air temperature and soil humidity. The highest tendency of nitrate increase was established in the drainage water from meadows in May: 15.2% from meadows and 8.9% from tillage land per year. The nitrate concentrations in drainage water increased less in October: 5.5% from meadows and 6.7% from tillage land per year.

Key words: nitrate nitrogen, concentration, peat soil, drainage, water

INTRODUCTION

An interchange of carbon, nitrogen, phosphorus and other elements is taking place between atmospheric air and soil (Heinrich et al., 2000; Bukantis et al., 2001). A simplified scheme of the migration of the biogenic materials that pollute surface waters within the environment of an agricultural field is the atmosphere – soil – drainage discharge – surface water. Changes in one environment make a certain impact on another environment. A lot of materials accumulate, vary and migrate in the soil which is a very slowly renewing natural resource. Under the influence of different degradation processes, the fertility and biological diversity of soils is decreasing, the cycles of their gases and nutrients are disturbed, therefore, the importance of soil preservation is acknowledged internationally (Dirvožemio..., 2006).

An especially complex and variable medium is peat soils. Organic matter with large amounts of carbon, phosphorus and nitrogen accumulates in peat which is usually saturated with water forming in natural marshes under conditions of oxygen shortage and acidic environment while plant residues accumulating carbon dioxide from the atmospheric air are dissolved. Different bacteria of low-lying marshy lands take and fix up to 100 kg ha^{-1} of nitrogen from the air every year (Howard-Wiliams et al., 1993; Mitsch et al., 2000). The nitrogen accumulated by peat reaches up to 1.3–4.5% of dry soil mass (Kuntze, 1988). The amount of total nitrogen in Lithuanian marshy soils varies from 0.3 to 3.6% (Zelionka, 1967; Motuzas et al., 1996).

When the groundwater level sinks, oxygen gets into drained peat soils. Under favourable aerobic conditions organic matter dissolves. During mineralization, carbon dioxide and nitrogen subdioxide gases pass into the atmosphere and phosphorus, potassium and nitrogen compounds enter the groundwater. Oxygen, which passes only to the upper soil layers of natural and poorly drained marshes, makes more favourable conditions for ammonia and nitrite oxidation, therefore, due to peat mineralization, minor losses of nitrogen are achieved – about 20 kg · ha^{-1} per year (Koerselman et al., 1992); 110–360 kg · ha^{-1} of nitrogen is mineralized in deeply drained peatbogs depending on the intensity of usage (Okruszko, 1993).

Part of mineral nitrogen compounds that are easily dissolved in water was leached down into deeper soil layers and washed out with the ground discharge: 3.0–6.0 kg · ha^{-1} is washed out from natural marshes and up to 150 kg · ha^{-1} from peat soils of cultivated grass meadows every year (Koerselman et al., 1992); in Holland when cultivating maize – up to 300 kg · ha^{-1} of nitrogen (Behrendt et al., 1996). In Lithuania, peat soil investigations were used to establish the quantitative indicators of nitrogen compounds or their leaching under different soil drainage (water regime) or usage conditions (Bukaveckas, 1963; Juškauskas, 1998; Malisauskas et al., 2005; Mašauskas et al., 2006).

The impact of flood water on the variation of nitrogen content in soil was investigated in the Lower Nemunas (Mališauskas

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et al., 2000). However, the variation and migration of this biogenic material depend also on other factors such as precipitation, air temperature, water regime, etc. (Motuzas et al., 1996; Matusevičius, 1998; Mališauskas, 1998; Treppel, 2000; Heinrich et al., 2000). Both global and short-term climatic changes can influence this impact.

Our objective was to establish the peculiarities of consistent patterns of nitrate variation in drainage water and its links with some climatic factors.

OBJECTS AND METHODS

The investigations were carried out in 1993–2007 on the right side of the Nevėžis valley, Vilainiai polder (Vilainiai, Kėdainiai Distr.). The variation of nitrate concentration in drainage water was also observed in the lakeside of Lėnas (Taujėnai, Ukmergė Distr.). The soils of the trial fields in Vilainiai are *Thaptohisti–Mollic* Fluvisols) (Buivydaitė et al., 2001). Soil density is 0.5–0.9, the density of solid phase is 2.1–2.5 g · cm^{-3}. Organic matter accounts for 20–50%, its dissolution degree is 40–60%. Alluvial deposits are medium loam according to the granulometric composition. The fields are drained by tile drainage. There is a meadow sown in one field in 1984, the other field was ploughed in spring 1997. Spring barley and rape seed were grown in rotation in the cultivated field. In 2002–2003 the field rested. The mowed meadows were fertilized with 60 kg · ha^{-1} of nitrogen; cereals were given additional 30 kg · ha^{-1} of phosphorus and potassium apiece. The hay yield was 5–10 t · ha^{-1} and grain 2.0–3.0 t · ha^{-1}.

The meadows of Lėnas lakeside were sown in 1980; they are drained by tile drainage. The soils of the first drainage system territory are *Bathiterric Histosols*. The ash content of peat reaches 10–15%, dissolution degree is 40–50, density 0.2–0.4, the density of solid phase is 1.6–1.8 g · cm–3. The soils of the second territory are Gleyic Podzols; according to the granulometric composition they are sandy loams on loams, density 1.1–1.5, solid phase density 2.3–2.8 g · cm$^{-3.}$ The content of organic matter in the layer of 0–30 cm was 13–17%.

Every five days the water regime was monitored in the Vilainiai polder (the level of groundwater and drainage discharge). Drainage water samples were taken from both objects every 1–2 months. The levels of nitrogen compounds in them were established by unified methods (Unifikuoti..., 1999).

The meteorological conditions are described on the basis of the data from the nearest meteorological stations in Dotnuva, Ukmergė and Panevėžys. Correlation links between the content of nitrates in soil and water and the affecting climatic factors were assessed by establishing reliability criteria of functional dependencies and differences (the correlation coefficient R and Student's test t_{η}, t_{fakt}). The nature of the investigated parameter trends was established by the Mann–Kendall test and the value and significance by Sen's estimate method. When establishing the significance of a trend, the lowest limit (p) was taken corresponding to the level of 0.35. The trends of a lower significance were considered insignificant.

RESEARCH CONDITIONS

Hydrometeorological conditions during the research period varied (Fig. 1). Two periods could be distinguished in the variation of annual precipitation. In 1997–2001 the amount of precipitation was close to the norm (88–96%), except the wet year 1998 (120% of the norm). The years 2002–2007 were dryer (70–80% of the norm), except 2004 of a normal humidity (94% of the norm) and the dampish 2007 (111% of the norm). Three year periods can also be distinguished in the variation of precipitation level when a more humid year went after two drier ones (1999–2001, 2002–2004, etc.). There is no such periodicity in discharge variation as it is determined by evaporation intensity depending on air temperature. The average annual air temperature was 1.3 °C, and during the vegetation period it was 0.6 °C above the norm. The warmest were the years 1999, 2000 and 2002, as well as 2003

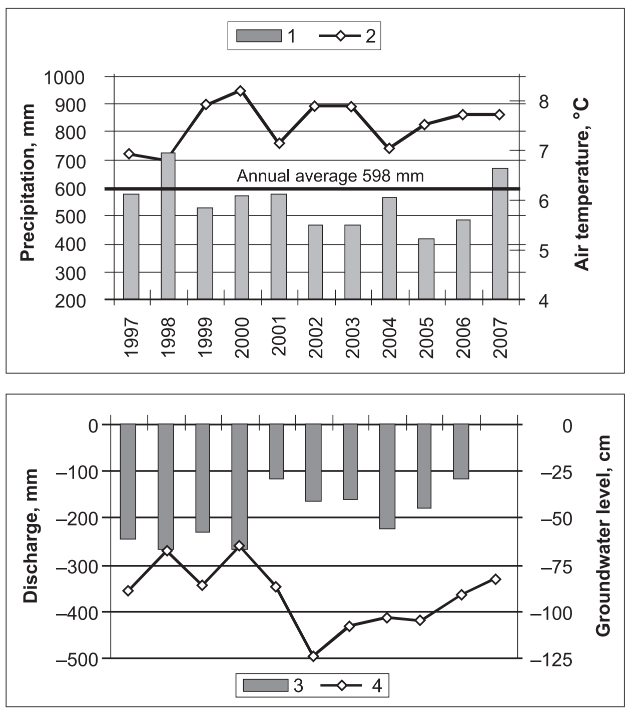

Fig. 1. Meteorological conditions and water regime in Vilainiai meadow during the study period: *1* – quantity of annual precipitation, *2* – average air temperature, *3* – drainage discharge, *4* – average groundwater level

Table 1. **Water regime indicators in Vilainiai polder during April–October**

Object	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Hydrothermic coefficient											
	1.2	2.0	0.9	1.6	1.4	0.6	0.9	1.4	1.0	1.1	1.6
Groundwater level from ground surface, cm											
Meadow	90	68	86	66	87	125	108	104	106	92	83
Crop field	87	59	74	74	88	126	110	107	108	100	72

when the average air temperature was by 1.7–2.0 °C higher than the norm.

The hydrothermic coefficient (HTK), which expresses the ratio between precipitation and air temperature, describes hydrometeorological conditions during the period of intensive plant vegetation. During the study period, the HTK showed a very dry vegetation period in 2002 and a very humid one in 1998. The years 2000 and 2007 were rather humid as well (Table 1).

Two distinct periods were also observed in the variation of discharge and groundwater level: a more humid period (up to 2001) when the average discharge was 226 mm and the average groundwater level was 78 cm from the soil surface, and a later, drier one when the mentioned indicators were 170 mm and 94 cm, respectively.

Data trends of hydrometeorological conditions during the study period showed a diverse nature of their variation. An increase in the annual air temperature reached about 0.7 °C and during the vegetation period about 1.0 °C. The annual precipitation trend showed decreasing tendencies (about 150 mm); similar, though not so pronounced tendencies of discharge decrease were observed. The variety trend of groundwater level showed a dropping tendency. The deepest position of groundwater was observed in 2002 and 2003.

RESULTS AND DISCUSSION

Variation and regularities of nitrate quantity in drainage water

Natural conditions and land use affected nitrate concentrations in drainage water as well. The variation tendency of water NO_3–N concentration in the Nevėžis valley (Fig. 2) was dependent on its variation in the soil. A lower variation was observed in the water of meadow drainage in which NO_3–N concentrations were 0.4–16.7 mg · l^{-1}. The concentrations in the discharge from a crop field (1.3–47.5 mg · l^{-1}) were 2–3 times higher than those from the meadow. As in the case of soil, nitrate concentrations in drainage water showed a leap in 2004–2007 when the concentrations increased 10 times compared with the previous period. The nitrate content increased both in the drainage water from the meadow and crop field. However, the absolute concentration values in the soil were 2–3 times higher than in the meadow, though, due to big variation differences, the reliability was not significant during the entire research period (difference criterion $t_{fakt} = 1.79 < t_{05} = 2.09$). Two periods are distinguished for nitrate concentration variations: 1997–2003 when NO_3–N concentrations in the mean discharge from the meadow and the cultivated field were 1.2 and 3.2 mg · l^{-1}, and 2004–2007 when the concentrations were 14.3 and 41.1 mg · l^{-1}

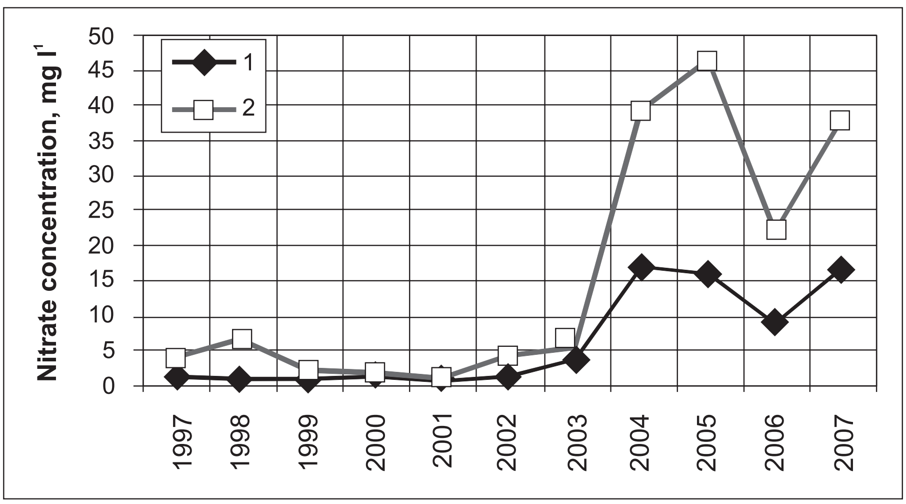

Fig. 2. Variation of annual nitrate concentration in drainage water of Vilainiai polder: *1* – meadow, *2* – crop field

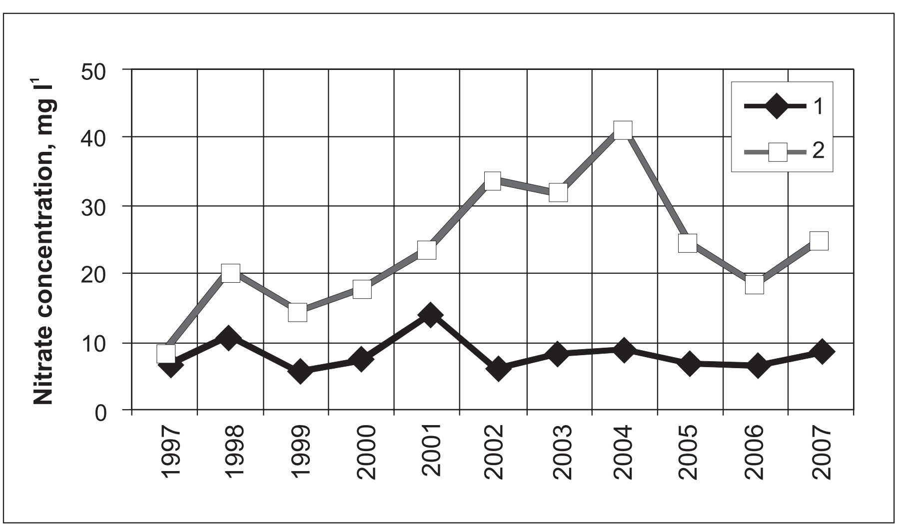

Fig. 3. Variation of nitrate nitrogen concentration in spring drainage water from Lėnas meadows: *1* – sandy loam, *2* – peat soil

respectively. The differences between NO_3–N concentrations in the water of the meadow and cultivated field drainage during the mentioned periods were more significant: in the first case the difference criterion $t_{fakt} = 2.32 > t_{05} = 2.18$, and in the second case $t_{fakt} = 4.02 > t_{05} = 2.45$.

A similar tendency of nitrate quantity variation can be observed in the drainage water from the peat soil meadow of Lėnas lakeside (Fig. 3). Nitrate content in water started increasing around 2002; the degeneration of the meadow sward due to intensive grazing was also a factor. In May 2007, the content of nitrate nitrogen was 20–30 mg · kg^{-1} in peat soil and 36 mg · l^{-1} in water. There was no such fluctuation of nitrate leaching in the mineral soil of the meadow. The average nitrate concentrations in the drainage discharge from peat soil and sandy loam differed two times and more (8.0 and 22.4 mg · l^{-1}, respectively). The difference between NO_3–N concentrations in the drainage discharge was significant ($t_{fakt} = 4.41 > t_{05} = 2.09$).

Relation between nitrogen concentrations in drainage water and meteorological and Hydrological Conditions

The impact of anthropogenic factors in experimental fields almost did not change. Therefore, it can be stated that the processes of mineralization of peat soil organic part and migration of varieous compounds determined the nature of nitrate content variation in soil and drainage discharge. The conditions of nitrate accumulation in soil and leaching by drainage water were obviously affected by soil temperature and water regime, which had been determined by the variation of climatic factors.

The impact of the groundwater level was different. When the water level was 80–90 cm from the soil surface, the content of nitrates in the 0–40 cm soil layer tended to increase. When the groundwater level was lower, the nitrate content decreased. A decreased humidity of soil determined a decrease of nitrate content. In summer, when groundwater level dropped to 100–150 cm from the ground surface and capillary feeding of the upper soil layers with water stopped, humidity decreased to 25–35% and the optimal soil humidity for nitrification processes was 40–70% of the total saturation (Возбуцкая, 1964).

The annual precipitation, air temperature and soil humidity had a less effect on nitrate concentration in drainage water (Table 2). Their dependency correlation links were weak and insignificant. The correlation links between nitrate concentration discharge and groundwater level were closer. The Student's test (90% certainty) showed that the latter factors influenced the nitrate content in water ($t_\eta = 1.48$–$1.69 > t_{10} = 1.4$). The effect of discharge on nitrate concentration is better seen when establishing dependencies of a shorter period (month, decade, 24 hours) discharge (Никаноров, 1989; Mališauskas, 1998).

The more nitrates are accumulated in soil, the more of them are leached with drainage water (Fig. 4) and get into the sources of surface water. The dependency reliability criterion is satisfactory ($t_\eta = 3.92 > t_{05} = 2.10$).

The regime of drainage discharge and the nature of variation of nitrate concentrations in water determined a considerable variation of nitrate washout. NO_3–N washout in the meadow

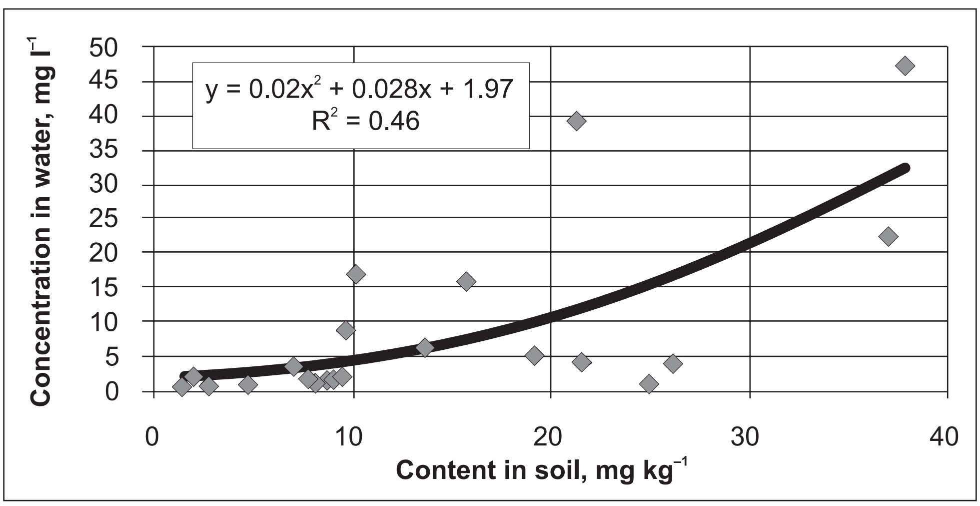

Fig. 4. Dependence of nitrate nitrogen concentrations in drainage water on its content in soil

Table 2. **Significance indicators of nitrate concentration dependencies in drainage water on hydrometeorological factors and nitrate nitrogen quantity in soil**

	Meadow			Crop field		
	Argument area	**Correlation coefficient R**	**Student's test t_η**	**Argument area**	**Correlation coefficient R**	**Student's test t_η**
Precipitation, mm	418–725	0.43	1.34	418–725	0.40	1.23
Discharge, mm	117–269	0.50	1.63	118–355	0.46	1.48
Air temperature °C	5.2–8.2	0.37	1.13	5.2–8.2	0.42	1.31
Groundwater level, cm	66–108	0.52	1.69	59–110	0.48	1.50
NO_3–N quantity in soil, mg · kg^{-1}	1.2–15.9	0.80	3.77	5.2–47.0	0.69	3.12

Note. Theoretical Student's t_{05} test = 2.31.

Table 3. **Tendencies on nitrate quantity increase (Mann–Kendall test) (1996/97–2007)**

No.	Place and time of sample taking	Average increase per year, %	Significance level
1	Vilainiai, drainage water, meadow, annual average	11.9	0.05
2	Vilainiai, drainage water, tillage, annual average	10.5	0.10
3	Vilainiai, drainage water, meadow, May	15.2	0.10
4	Vilainiai, drainage water, tillage, May	8.9	0.10
5	Vilainiai, drainage water, meadow, October	5.5	0.25
6	Vilainiai, drainage water, tillage, October	6.7	0.20
7	Lėnas, drainage water, sandy loam, annual average	1.9	0.25
8	Lėnas, drainage water, peat, annual average	8.2	0.10

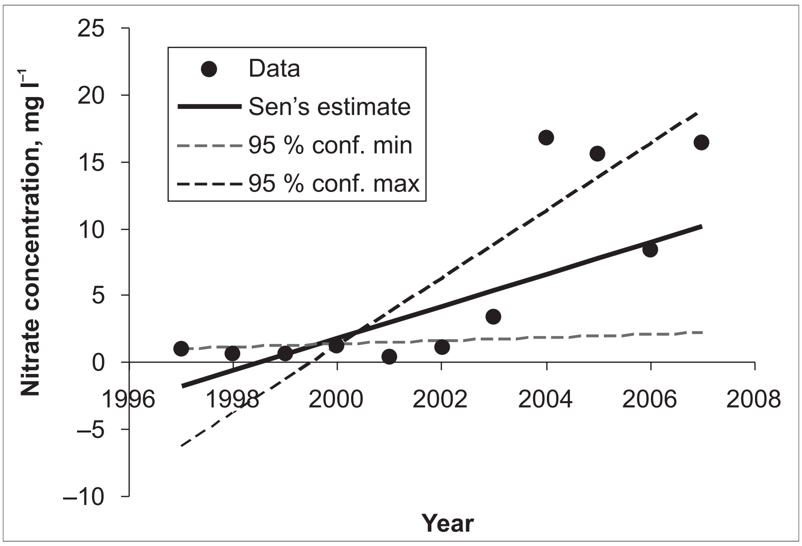

Fig. 5. Trend of nitrate concentration in meadow drainage water

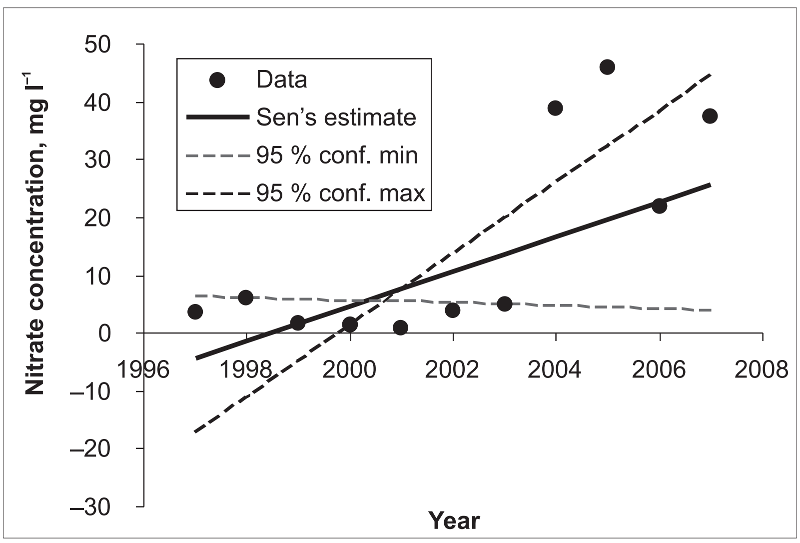

Fig. 6. Trend of nitrate concentration in tillage land drainage water

was 8.5 ± 11.8 (1.2–38.2) and 26.2 ± 38.8 (3.1–63.3) kg · ha^{-1} in the crop field.

Variation tendencies of nitrate quantity in drainage water

To establishing the tendencies of nitrate content variation, the Mann–Kendall and Sen's estimation were used. The test results showed that the tendencies of all indicators, except the hydrothermic coefficient and precipitation, were rising: the indicators measured during the research period were increasing (Table 3).

The highest increasing tendency of nitrate content was established in the drainage water from meadows in May: 15.2% from meadows and 8.9% from tillage land per year. Nitrate concentration in drainage water increased less in October: 5.5% from meadows and 6.7% from tillage land per year.

On average, the highest variation of nitrate concentration during the research period was observed in drainage water from meadows – 11.9% each year (Fig. 5). A slightly lower increase was recorded in drainage water from tillage land – 10.5% each year (Fig. 6).

Sen's estimation showed that nitrate content increased very unevenly during a year and depended on the soil, but mainly on land tillage. The hydrothermic coefficient was constant during the study period, whereas precipitation decreased a little, although the decrease was statistically of little significance (p = 0.25).

CONCLUSIONS

1. The established dependency indicators show that a greater impact on nitrate concentration in drainage water under the study conditions was exerted by discharge and groundwater level regime (r = 0.46–0.48) and a smaller one by a variation of annual precipitation, soil humidity and air temperature (r = 0.40–0.42).

2. The content of organic matter in soil determines the extent of its leaching by drainage. Nitrate concentrations in the drainage water draining peat soil and the content of nitrate washout from tillage land was higher compared with the meadow as well as their content in peat soil. Nitrate concentration in mineral soil which contained 5–7 times less organic matter, as well as in the drainage discharge from it was about 2.5 times lower as compared with that in peat soil. The content of nitrates washed out from mull fluvisol meadows together with drainage discharge averaged to 8.5 $kg \cdot ha^{-1}$, and it was 26.2 $kg \cdot ha^{-1}$ from tillage land.

3. The highest increasing tendency of nitrate quantity was established in drainage water from meadows in May: 15.2% from meadows and 8.9% from tillage land per year. Nitrate concentration in drainage water increased less in October: 5.5% from meadows and 6.7% from tillage land per year.

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NITRATŲ KIEKIO DIRVOŽEMYJE IR DRENAŽO VANDENYJE KAITA DURPŽEMIŲ DEGRADACIJOS PROCESE

Santrauka

1997–2007 m. atlikti nitratų kiekio durpžemiuose ir juos sausinančio drenažo vandenyje kaitos ir priklausomybės nuo metinių kritulių, vidutinės oro temperatūros, nuotėkio, gruntinio vandens lygio ir dirvožemio drėgmės tyrimai. Puveningo salpžemio dirbimas auginant javus skatino nitratų kaupimąsi dirvožemyje ir jo išplovimą drenažu. Drenažo vandenyje pievoje vidutinės nitratų koncentracijos siekė 5,95, dirbamojoje žemėje – 16,94 $mg \cdot l^{-1}$, o išplovos – atitinkamai 8,5 ir 26,2 $kg \cdot ha^{-1}$. Mineraliniame dirvožemyje, kuriame organinių medžiagų buvo 5–7 kartus mažiau, palyginti su durpžemiu, nitratų koncentracija vandenyje buvo apie 2,5 karto mažesnė. Glaudesnis funkcinis ryšys yra nitratų kiekio dirvožemyje ir vandenyje su drenažo nuotėkiu ir gruntinio vandens lygiu (r = 0,46–0,48) bei silpnesnis – su krituliais, oro temperatūra ir dirvožemio drėgme (r = 0,40–0,42). Didžiausia nitratų drenažo vandenyje didėjimo tendencija nustatyta iš pievų gegužę – 15,2% ir 8,9% iš dirbamos žemės per metus. Nitratų koncentracija drenažo vandenyje mažiausiai didėjo spalį – 5,5% iš pievų ir 6,7% iš dirbamos žemės.

Raktažodžiai: nitratų azotas, koncentracija, durpžemis, drenažas, vanduo