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EFFECT OF A LAND RECLAMATION SYSTEM ON THE VOLUME AND SEASONALITY OF NITRATE RUNOFF FROM CROPLANDS

Józef Koc, Kamil Solarski, Andrzej Rochwerger

Katedra Melioracji i Kształtowania Środowiska
Uniwersytet Warmińsko-Mazurski w Olsztynie

Abstract

The paper contains the results of eight-year-long studies on the runoff of nitrates from heavy soils used as croplands. The runoffs of nitrates from a drainage catchment and a catchment drained with ditches were compared. The drainage system was found to carry away twice as much water, with a five-fold higher concentration of nitrates and 20-fold higher load of nitrates, than the system of ditches. High runoff of nitrates (22 kg ha^{-1} annually) from the soils drained by drains was distributed quite evenly throughout the year, with maximum peaks in March and June. Nitrate runoff through the system of ditches was low (1.15 kg ha^{-1} annually), reaching maximum peaks in March and April (62% of the load), but disappearing in the summer.

Key words: nitrates, runoff from soils, draining system.

WPŁYW SYSTEMU MELIORACYJNEGO NA WIELKOŚĆ I SEZONOWOŚĆ ODPŁYWU AZOTANÓW Z GLEB UPRAWNYCH

Abstrakt

W pracy przedstawiono wyniki 8-letnich badań odpływu azotanów z gleb ciężkich użytkowanych ornie. Porównywano odpływ azotanów ze zlewni drenarskiej i zlewni odwadnianej rowami. Stwierdzono, że system drenarski odprowadza 2-krotnie więcej wody o 5-krotnie wyższym stężeniu azotanów i 20-krotnie wyższym ich ładunku niż system rowów. Z gleb odwadnianych drenami wysoki odpływ azotanów (22 kg rocznie z 1 ha) rozkładał się równomiernie w ciągu roku, z maksimum w marcu i czerwcu. Odpływ azotanów systemem rowów był niewielki (1,15 kg rocznie z 1 ha), z maksimum w marcu i kwietniu (62% ładunku) i zanikiem odpływu latem.

Słowa kluczowe: azotany, odpływ z gleb, system odwodnienia.

prof. dr hab. Józef Koc, pl. Łódzki 2, 10-727 Olsztyn, e-mail: jozef.koc@uwm.edu.pl

INTRODUCTION

The natural circulation of water and chemical components has been seriously disturbed in the past century due to the rapid human population growth, development of civilisation and, mainly, the growth of industries, civil engineering, transportation, and intensive agricultural practices including widespread application of mineral fertilizers, chemical pesticides and herbicides, large densities of farm animals, and errors in agronomic techniques. All those factors have lead to excessive accumulation of noxious substances in soil. Land reclamation carried out for the last 150 years, with a preference for water draining systems, has accelerated such unwanted results.

Contemporary agriculture has disrupted the natural, harmonious and relatively closed matter cycling in ecosystems by introducing additional amounts and new substances (fertilizers, plant protection chemicals), as well as by using techniques to loosen soil, which accelerate water circulation. Nitrogen is among the elements whose natural circulation has been subjected to biggest modifications, as it is one of the essential constituents in agricultural production and is sensitive to habitat-related conditions. High productivity of nitrogen favours its application at rates exceeding the optimum nutritional requirements of crops, as a result of which it is not used up completely (FOTYMA 1996, FOTYMA 1997, SAPEK 1996). This means that one of the early signs of environmental contamination caused by agriculture is the occurrence of large, frequently dangerous amounts of nitrates in ground and surface waters in rural areas (FOTYMA 1996).

Often there are differences between the volume of nitrogen required by crops at a given time and the actual amount of available nitrogen forms present in soil. Because of their good availability to plants, nitrates are willingly used as N fertilizers, especially when the release nitrogen from soil resources and organic fertilizers is slow. Nitrates which have not been taken up by plants undergo other types of sorption and can easily transfer in soil. In our climate, water in soils travels down the profile for most of the year (except summer) and through a draining system reaches open water bodies. Nitrates are unwanted in water reservoirs due to their contribution to eutrophization and secondary contamination as well as the fact that nitrates and nitrate derived metabolites are harmful to aquatic organisms.

For many years we have been aware of the relationship between the concentration of nitrates in waters and intensive agricultural production with high levels of mineral fertilization or large animal farms with inadequate storage of manure (KOC et al. 1996). The code of good agricultural practice is expected to prevent this (FOTYMA 1996), but will it suffice? The runoff of nitrates to surface waters should be related to systems of land reclamation, which were created with an aim of facilitating the fastest possible draining of water, which in turn is responsible for quicker warming of soils and initiation of biological process as well as the runoff of biogens (KOC, SZYMCZYK, 2003, LIPIŃSKI 2003, MILLER et al. 2001). The role of land reclamation systems in the removal of biogenic substances to waters is still debatable. Stabilization of groundwater on a level that is optimal for plants and earlier warming of soils in spring are favourable for the development of the root system and the uptake of nutrients from deeper layers of soil. Lack of water draining not only limits the runoff of biogenic compounds from soil but it is also responsible for oxygen deficit and favours denitrification of nitrates. The problem lies in the regulation of water draining and water retention within agricultural ecosystems during summer water deficits. This would enable biogens to return to the agricultural circulation. Implementation of these concepts in practice and their efficiency depend on the recognition of runoff of biogens through land reclamation systems.

The aim of this study has been to determine the dynamics of nitrates runoff from agricultural catchments and to recognize the effect of water draining systems on the dynamics of this process.

METHODS

The study was carried out in the Olsztyn Lake District in 1992–1999. The district lies in the postglacial area, with typically diversified land relief and varied geomorphologic and soil structure. Hills, often with steep slopes and largely diversified soils, are a characteristic physiographic factor in the area. Depending on the origin (boulder or fluvioglacial sediments) soil differs in granulometric composition and the resulting physicochemical properties or agricultural usability. Two catchments, both under agricultural use, were selected for the tests. The catchments where the observations and tests were conducted lie directly behind the fourth row of terminal moraines, which stretches from Morąg via Gietrzwałd, Stawiguda (10 km south of Olsztyn) and Barczewo towards Mikołajki (SOLARSKI et al. 1996, UGGLA 1956).

Catchment 1. The area of 72.8 ha drained with a ditch. The land configuration – hilly, 69% of the area covered with slopes at an angle up to 6%; 21% of the area has slopes from 6 to 12%. Slopes from 12 to 18% cover about 9% of the total area and 1% of the catchment lies on slopes reaching over 18%. Agricultural use. Typical brown soils are dominant (approximately 40%). They are mainly compact soils, formed from clay and silty clay, difficult to cultivate and not easily aerated. Pseudopodzolic soils (silty), which make up 37% of the area, are mainly composed of medium and light clays and weak loamy sands on clay or silty clay. The soils found in land depressions, which constitute 10% of the area, are used as grassland and belong to muck soils. Forests occupy 8% of the catchment and lie on light loamy sands. Arable land covers 75% of the area; other types of land use make up 7% of the area.

Catchment 2. The area of 8 ha, drained by an unsystematic system of drains. It is basin-shaped, with rather long slopes, inclined towards the line of water runoff. The fall of the ground of less than 6% angle occurs on 18% of the catchment's area; 6 to 12% – on 55% of the area; 12–18% on 20% of the area, and >18% on 7% of the area. The soils in the catchment belong to medium soils – strong loamy sands (42%) and light clay and loamy sands (43%), light sandy soils (15%).

Crop rotation systems tested in both catchments were identical, involving the following crops (in brackets – the average yield in t/ha): spring barley (2.6), winter wheat (4.9), winter triticale (3.7), winter rye (3.6), oats (2.5), mixed cereals (2.5), winter oilseed rape (3.3), lupine (2.5), horse bean (2.8), maize (3.0) and potatoes (25.0). Depending on the type of soil texture and fertility, type of soil management, water conditions and agricultural use, the following fertilization was applied to each crop (plants): from 120 to 215 kg NPK ha^{-1} on average, with the lowest fertilization rate, from 40 to 60 kg NPK ha^{-1} under winter rye and spring barley, to around 350 kg NPK ha^{-1}, supplied to winter oilseed rape (SOLARSKI 2002).

In both catchments, measurements of the water runoff were made every ten days; water samples for analyses were collected once a month. The water samples were analysed to determine nitrates by colorimetric method, using disulfophenol acid.

RESULTS

Transformation of nitrogen compounds in soil, their uptake by plants and transfer into deeper layers of the soil profile, they all depend on the current meteorological conditions. The course of the weather conditions was analysed in hydrological years, i.e. from 1st November to 31st October. The meteorological conditions during the years under study (1998–1999) were highly varied, which is also typical of the area analysed, situated in a transitional zone of the Atlantic and Continental climates (Tab. 1).

The average annual precipitation for one hundred years was 605 mm. The period under study was similar to the long-term data in terms of the total rainfall, but slightly warmer, with the mean annual temperature of 7.4°C, versus the mean annual temperature for one hundred years of 6.8°C. Some differences between the years occurred, from an extremely dry and cold year 1996 to warm and humid year 1995. Only one year was close to the long-term average for precipitation (1992), whereas three years were closer to a humid year (1993, 1994 and 1999), and two were drier (1997 and 1998). In respect of temperatures, only one year could be considered as a warm one (1995) and one – to be cold (1996). The other years were slightly warmer than the long-term average.

Table 1

Meteorological conditions during the years under study (data supplied by the meteorological station in Olsztyn)

Hydrological year	Parameter	Year 11-10	Winter 11-04	Summer 05-10	Spring 03-04	08-09	10-11
1992	*a*	628.0	288.0	340.0	115.0	188.0	108.0
	b	8.0	1.7	14.4	4.3	16.1	4.2
1993	*a*	679.0	252.0	427.0	52.0	146.0	36.0
	b	7.4	1.7	13.1	4.3	13.0	2.2
1994	*a*	690.0	378.0	312.0	175.0	97.0	155.0
	b	7.4	0.9	13.9	5.2	15.8	4.9
1995	*a*	701.0	321.0	380.0	102.0	152.0	58.0
	b	8.4	2.3	14.4	4.7	15.0	5.2
1996	*a*	415.0	125.0	290.0	24.0	71.0	84.0
	b	5.7	-2.1	13.5	2.6	14.1	5.5
1997	*a*	556.1	136.2	419.9	59.5	44.0	95.4
	b	7.1	0.2	13.9	3.0	15.7	4.2
1998	*a*	550.0	196.7	353.3	80.0	101.4	91.9
	b	7.8	2.2	13.5	4.7	13.9	1.9
1999	*a*	671.3	268.5	402.8	155.0	87.2	82.3
	b	7.5	0.5	14.5	6.1	15.8	5.0
Mean from 1992-1999	*a*	611.3	245.7	365.6	95.3	110.8	88.8
	b	7.4	0.9	13.9	4.4	14.9	4.1
Long-term mean 1881-1995	*a*	605.2	225.9	379.3	70.7	129.0	90.7
	b	6.8	0.1	13.4	3.2	14.4	3.9

a – rainfall in (mm)
b – air temperature in (^{o}C)

According to the data presented in Table 1, the years 1992–1994 and 1997–1998 were warm with the total precipitation close to the normal level, and can therefore be considered as favourable to denitrification. The year 1996 was the least favourable to denitrification due to lower temperatures, whereas the year 1995 was wet, which reduced the availability of oxygen in soil. Transfer of nitrates in soil should be encouraged mainly by large amounts of rainfall at normal or depressed evapotranspiration, which depends on the amount of energy in the environment, as indicated by temperature. Transfer of substances in soil, including nitrates, is not favoured by a period of dry weather prior to the period under study. Consequently, the largest runoff should be expected in 1994 (a wet year after wet six months including summer).

Denitrification and nitrate runoff from soil are influenced by the course of weather conditions in each shorter period of time. Thus, the process of nitrate formation and runoff was favoured by warm and wet winter half-year in 1991/92, 1992/93,1993/94,1994/95 and 1998/99, whereas cold and dry winter such as in 1995/96, 1996/97 and 1997/98 was unfavourable to these processes.

In the six months of wintertime, the most important for nitrate runoff is the early spring (March-April), when snow cover melts and waters retained in winter begin to flow away. As regards this time of year, the seasons of 1993, 1995, 1997 and 1999 were favourable to nitrate runoff, in contrast to 1992 and 1998.

In summer half-year, especially unfavourable conditions migration of nitrates appear when evapotranspiration is high and drought conditions prevail while plants uptake nitrates – such conditions prevail in August and September. October and November, on the other hand, are favourable to the creation and transportation of nitrates, because soil is still warm and the uptake of nitrates is limited to winter crops and perennial plants. Such favourable conditions for nitrate runoff from soils occurred in 1994.

Based on the eight-year-long study, the test objects were characterised in terms of their hydrological properties and nitrate runoff (Figures 1–3). Significant differences in the levels of the characteristics investigated were discovered. In the catchment with a drainage system the runoff of water was twice as high as in the catchment drained by a system of ditches. Furthermore, the concentration of nitrates was 15-fold higher and the load of nitrates was 20-fold larger. It is typical for water discharge to grow from the beginning of a hydrological year (November) until March in an area drained by ditches or until April if drainage systems are used, which is when water flow reaches its maximum to decline afterwards. In the case of ditches, the March maximum is 50-fold as high as the minimum water discharge observed in August. In the drainage catchment, the water discharge in summer was significantly higher than in the catchment with ditches, reaching 45% of the April maximum. Draining with ditches causes large differences in seasonal water discharges, much larger than drainage systems (Figure 1).

Concentration of nitrates in water obtained its maximum levels from January to April in winter, and the maximum discharge of nitrates occurred in March and April, while the minimum water runoff was observed in August (Figures 2 and 3). These relationships were analysed against the background of meteorological conditions in each year, with special attention paid to the periods of March-April and August-September. The results of the analyses, presented in Fig. 1 and 3, indicate that the runoff of nitrates from soils to surface waters is directly connected with the efficiency of water draining systems. The measurements showed an indisputable relationship between the volume of water discharged from soils with the land reclamation system and with the weather conditions (Table 2).

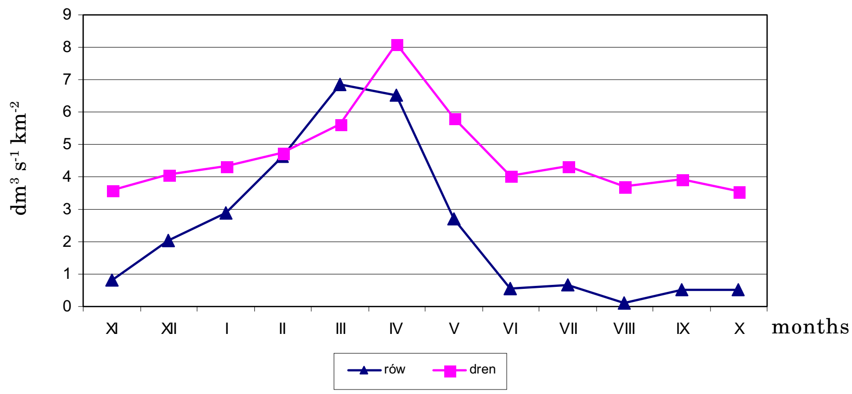

Fig. 1. Effect of a draining system on the mean unit runoffs in 1992–1999

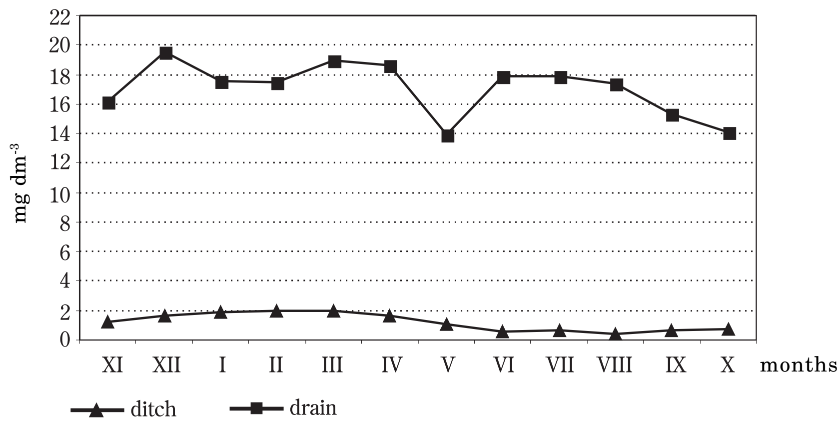

Fig. 2. Effect of a draining system on the mean concentration of nitrates in 1992–1999

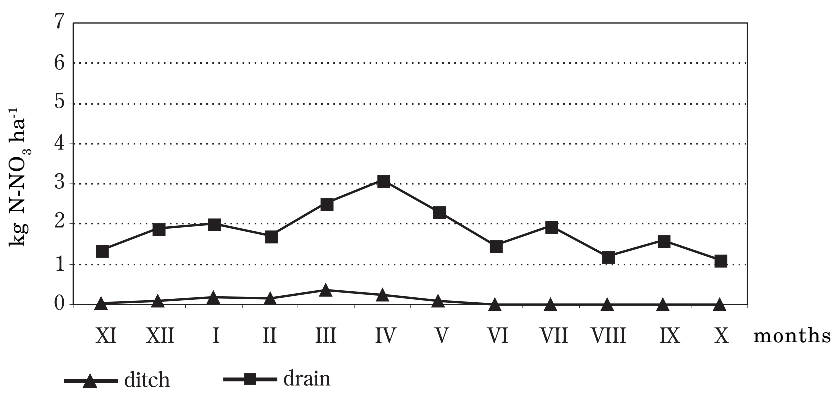

Fig. 3. Effect of a draining system on the runoff of nitrate load in 1992–1999

Table 2

Runoff of water from agricultural catchments in mm

Year	Draining system	Time period in months					
		11-10	11-04	05-10	03-04	08-09	10-11
1992	ditches	35	23	12	15	3	5
	drains	64	34	30	14	11	10
1993	ditches	86	74	12	38	6	2
	drains	105	52	53	21	19	19
1994	ditches	202	172	30	137	1	2
	drains	222	112	110	62	29	29
1995	ditches	73	58	15	20	3	2
	drains	228	119	109	49	32	30
1996	ditches	39	25	14	22	0	1
	drains	143	87	56	44	16	15
1997	ditches	31	12	19	7	1	9
	drains	82	43	39	16	13	14
1998	ditches	105	94	11	36	1	2
	drains	178	90	88	39	25	25
1999	ditches	34	34	0	9	0	0
	drains	151	95	56	48	17	9
Mean from 1992-1999	ditches	76	62	14	36	2	3
	drains	147	79	68	37	20	19

Volumes of discharged water from the two neighbouring catchments, with identical natural conditions and the crop cultivation system, differed two-fold. For the period of eight years, the system of ditches carried away 12% of the annual rainfall, and the drainage system – 24%. The differences in the draining capacity of the land reclamation systems were small in winter, but in the summer half-year, the underground drains carried away five as much water as open ditches. This is due to the fact that the drainage system is denser and can penetrate the soil more efficiently. Besides, in a drainage system there is no risk of halting the runoff.

Moreover, in summer, water in the ground between ditches (which is larger in area that that between drains) evaporates, and the runoff of the water which does flow into ditches is halted by plants. The effect of these two factors becomes stronger in late summer, when drains carry away ten times as much water as ditches.

Because of such differences between the two types of water draining systems, the runoff of water through drains is more uniform throughout the whole year, while the water discharge through ditches was not only smaller, but in 82% occurred in the winter half-year.

To assess the influence of meteorological conditions on water runoff we compared the runoffs from particular years, for example the years 1993 and 1994. With the precipitation and temperatures being similar, the water runoff in 1994 was 2.5-fold higher through ditches and 2-fold higher through drains than in 1993. The difference can be attributed to the fact that the year 1993 was preceded by a drier and warmer summer in 1992, as a result of which the soil contained smaller reserves of water. The year 1994, in contrast, was preceded by a wet summer. For further comparison, the year 1995 was wet and came after a wet year, but at the same time it was the warmest year, which meant that the evapotranspiration was the highest and the water runoff through ditches was smaller. The precipitation-runoff route is longer in a draining system with ditches, thus evapotranspiration is more likely to take place. In the case of drains, the precipitation-runoff route is shorter, therefore evapotransipartion occurs less readily and the water runoff through drains was similar in both years.

Among the shorter time periods compared (two-month), the largest water runoff was observed in early spring (March-April). The runoff was significantly higher than in the other bimonthly periods considered. The early spring water discharge is caused by the melting of snow cover, current precipitation and lack of plant cover. This was particularly evident in 1994, when early spring was extremely wet, and the soil permeated with water could not retain further rainfall.

Water runoff from soil was accompanied by improved soil aeration and nitrification of nitrogen, which meant that higher concentration of nitrates was found in the waters from the drained objected (Table 3).

On the other hand, a positive correlation was discovered between the mean annual temperature and concentration of nitrates. An exception was the year 1995, when large rainfall was accompanied by the highest temperature. It was therefore possible to observe some inhibition of oxygen supply to soil for soil transformations, and oxygen consumption for carbon mineralization, especially in summer, at high temperatures. This finding is confirmed by the fact that a decrease in the concentration of nitrates in water in the drains was lower, as the water transport was more efficient.

In the same year, i.e. in 1994, winter and early spring in particular were warm compared to the long-term data, which was favourable to the runoff of nitrates, because at the temperature of around 5°C nitrification was not slowed down. The concentration of nitrates resulted from the combination of two factors - temperature and oxygen supply. Concentrations of nitrates in water from the drainage system were similar in the winter and summer half-year periods. Some larger dissimilarities in nitrate concentra-

Table 3

Mean concentration of nitrates in waters flowing from cropland soils (mg $N\text{-}NO_3$ dm^{-3})

Year	Draining system	Time period in months					
		11-10	11-04	05-10	03-04	08-09	10-11
1992	ditches	2.36	3.53	0.95	4.21	0.34	2.42
	drains	10.56	12.76	8.37	22.00	2.00	12.94
1993	ditches	1.94	3.01	0.87	2.63	0.48	0.48
	drains	19.41	19.45	19.37	23.58	22.73	21.58
1994	ditches	1.23	1.71	0.74	1.83	0.42	0.89
	drains	24.09	24.36	22.59	18.13	23.04	20.11
1995	ditches	0.94	1.54	0.35	1.47	0.36	0.36
	drains	14.89	16.35	13.43	18.58	13.70	16.35
1996	ditches	0.52	0.43	0.63	0.42	0.67	0.47
	drains	24.24	23.97	24.50	19.95	25.94	17.96
1997	ditches	1.03	1.18	0.89	2.72	0.96	0.99
	drains	16.44	21.35	11.53	2.17	12.36	7.03
1998	ditches	0.90	0.97	0.77	0.65	0.42	0.18
	drains	10.55	11.19	9.49	12.56	9.55	7.50
1999	ditches	0.54	0.36	0.71	0.04	1.63	3.34
	drains	11.13	11.07	11.19	13.12	12.90	0.06
Mean from 1992-1999	ditches	1.18	1.59	0.74	1.75	0.66	1.14
	drains	16.41	17.56	15.06	16.26	15.28	12.94

tions between certain years can be attributed to soil processes and dilution with water. As regards waters carried away through ditches, higher concentration of nitrates was usually determined in winter. The ratio between the concentration of $N\text{-}NO_3$ in winter and summer waters was on average 2.1:1, and 1:1.4 in summer half-year (in two years only the ratio was reverse, but this was due to the fact that those two winters were freezing cold, which slowed down nitrification, and in the following summers the water flow was minimal).

The following relationship appeared. Efficient draining favoured oxygen processes and nitrification. This was compounded by the effect of temperatures. In warm winters, and especially in warm early spring seasons, temperatures above zero favour nitrification and nitrate runoff with waters. On the other hand, some obstacles to water runoff as well as excessive amounts of water in soil slow down nitrification. Should the latter be combined with high temperatures (summer), oxygen deficits and depressed levels of nitrogen are likely to occur. The concentration of nitrates in drainage waters exceeds the safety limit, which is 50 mg NO_3 dm^{-3} for potable water (*Ordinance of the Ministry of Health*, 2000).

The runoff of nitrates from soil is an aggregate of the amount of the water discharged and the amounts of nitrates it contains. As a result, meteorological conditions often had similar influence on both factors (runoff and concentrations). Consequently, some significant interdependence was observed between these factors and their effect on the amounts of nitrates carried away from the croplands examined (Table 4).

The annual runoff ranged from 0.04 kg per ha to 49.44 kg N-NO_3 per ha. Variations in the runoff were caused by both the type of a draining system and the weather conditions. The drainage system carried away on average 22.2 kg N-NO_3 per ha annually, ranging from 7.1 to 49.6 N-NO_3 per ha. Under the same conditions, soils drained by ditches had an outflow of 1.2 kg N-NO_3 per ha annually, ranging from 0.04 to 3.64. These figures confirm our previous studies (KOC, SZYMCZYK 2003). The runoff of nitrates in hydro-

Table 4

Mean concentration of nitrates in waters flowing from cropland soils (mg N-NO_3 dm^{-3})

Year	Draining system	Time period in months					
		11-10	11-04	05-10	03-04	08-09	10-11
1992	ditches	1.06	0.91	0.15	0.61	0.01	0.18
	drains	7.13	4.93	2.21	2.95	0.47	1.45
1993	ditches	2.43	2.32	0.10	1.12	0.06	0.01
	drains	20.7	10.32	10.40	4.79	3.67	3.81
1994	ditches	3.64	2.26	0.38	2.52	0.01	0.04
	drains	49.55	25.49	24.06	11.27	6.91	5.71
1995	ditches	1.00	0.95	0.05	0.29	0.02	0.01
	drains	34.55	19.38	15.17	8.75	7.56	4.55
1996	ditches	0.18	0.11	0.07	0.09	0.02	0.01
	drains	34.01	20.55	13.46	8.61	4.49	1.09
1997	ditches	0.31	0.16	0.15	0.12	0.01	0.04
	drains	9.16	6.50	2.66	1.62	0.01	0.51
1998	ditches	0.79	0.68	0.11	0.23	0.01	0.01
	drains	13.86	9.40	4.45	4.97	1.52	0.01
1999	ditches	0.04	0.04	0.00	0.00	0.00	0.00
	drains	8.88	4.54	4.34	2.17	0.01	0.01
Mean from 1992-1999	ditches	1.18	0.93	0.13	0.62	0.02	0.04
	drains	22.23	12.64	9.59	5.64	3.08	2.14

logical half-years was highly variable. In soils drained by ditches, 87% of the annual load of nitrates was carried away in winter, with just 13% discharged in summer, which was similar to the annual distribution of water outflow. As regards waters drained by the drainage system, the load of nitrates carried away in summer reached 43% of the average annual runoff, and the water outflow equalled 46% of the annual total. The influence of meteorological conditions was such that in dry years the runoff from summer half-year decreased to 30% of the average annual runoff in the object with the drainage system. In the case of open ditches, the summer outflow was hardly measurable. Nitrates from ditch water in the summer half-year were taken up by plants, as a result of which water which flew into the ditches was used up by plants rather than discharged further.

Around 50% of the nitrate runoff in the winter half-year fell to March and April in the case of drains versus 60% in the ditches. Later on, in late summer (August-September) and autumn (October-November), the runoff of nitrates decreased, although in the drains, the runoff measured amounted to 15% of the annual runoff late summer and 10% in autumn. At the same time, the runoff of nitrates through ditches decreased to the minimum. Such a relationship occurred generally in all the years. However, nitrate runoff through the drains was favoured by high precipitation. As for ditches, the runoff of nitrates from soils is small, less than 10% of the fertilization rate, and occurs mainly in early spring (March-April). Draining ditches function like a barrier which prevents the runoff of nitrates from croplands. As regards drainage systems, the amount of nitrates carried away varies from over 10% to 40% of the fertilization rate and occurs throughout the whole year, but is more intense in early spring (March-April). The load of nitrates from croplands drained through a drainage system is dangerous to water reservoirs (VOLLENWEIDER 1968).

In the light of the nitrogen balance studies in soils of croplands, it can be assumed that most of the excessive amounts of nitrogen is removed from croplands with drainage waters. In the case of soils drained with ditches, the runoff of nitrates is minimal, and most of nitrogen is transferred to deeper groundwaters, where it is reduced due to lack of oxygen.

CONCLUSIONS

1. The runoff of nitrates from croplands depends on meteorological conditions and type of a draining system. In drained heavy soils, nitrate runoff amounts to an average 22 kg $N\text{-}NO_3$ per 1 ha annually, although it can reach as much as 50 kg, posing a threat to open surface waters. From an identical area drained with ditches, the runoff of nitrates is 20-fold lower and does not threaten open waters.

2. The runoff of nitrates is connected with the volume of waters flowing off the land and the intensity of nitrification, as indicated by the concentration of nitrates in waters. In drainage waters, nitrates can exceed 50 mg $N\text{-}NO_3$ per 1 dm^3, which means that the water is unsuitable for human or animal consumption.

3. Waters from draining ditches contain less than 10 mg $N\text{-}NO_3$ per 1 dm^3, declining to under 1 mg $N\text{-}NO_3$ per 1 dm^3 in summer. This is due to biological sorption of nitrates.

4. The runoff of nitrates with drainage waters from heavy soils continues throughout the whole year, being more intense in March and April. The runoff of nitrates from croplands drained with ditches occurs in winter, reaching the maximum level in March and April, and the minimum (down to complete disappearance) in August.

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