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INFLUENCE OF THE TYPE OF SOIL DEWATERING AND LAND USE ON THE DYNAMICS OF CONCENTRATIONS AND VOLUME OF NITROGEN DISCHARGED FROM AGRICUTLURAL AREAS

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Abstract

Studies on the dynamics of concentrations and discharge of nitrogen load through draining systems were carried out in Olsztyn Lake District (Pojezierze Olsztyńskie) from 1994 to 2007. For the tests, three basins were selected: an agricultural basin drained with a drainage system, an agricultural and forested basin drained with a network of ditches and drains, and an agriculrual basin with a large forest cover (ca 30%), drained with ditches. The discharge of water through the draining facilities was measured every two weeks, and once a month, $N\text{-}NO_3$, $N\text{-}NO_2$, $N\text{-}NH_4$ as well as Kjeldahl nitrogen were determined. It has been demonstrated that the volume of discharged water carried away through draining systems depends primarily on the amount and distribution of atmospheric precipitation, epsecially during the winter half-year. The dynamics of concentrations and loads of nitrogen in water discharged via draining systems varied with time and depended not only on the amount and distribution of precipitation over a year and in the multi-year period, but also on the type of land use in a given basin and a draining system. It was also found out that intensive rainfall in summer only slightly increased the discharge of water from the basinm drained with the drainage system. The load of total nitrogen flowing away through the draining systems from agricultural basins was closely connected with the amount of discharged water and water levels of mineral nitrogen compounds, especially $N\text{-}NO_3$. The highest nitrogen loss from drained areas appeared in spring, which was associated with the seasonal character of water outflow, culmunating in March-April. The highest concentration of total nitrogen (16.69 mg dm^{-3}) was determined in water discharged through the network of ditches and drains, but due to a more intensive dewatering of so-

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ils, a higher total nitrogen load (on average 33% more) was discharged through drains. Per 1 ha of an agricultural basin, the annual outflow of total nitrogen was up to 13.13 kg, including 12.04 kg of mineral nitrogen.

Key words: nitrogen, drains, ditches, agricultural basin, draining systems.

WPŁYW SPOSOBU ODWODNIENIA I UŻYTKOWANIA GLEB NA DYNAMIKĘ STĘŻENIA I WIELKOŚĆ ODPŁYWU AZOTU Z OBSZARÓW ROLNICZYCH

Abstrakt

Badania nad dynamiką stężenia i odpływu ładunku azotu systemami melioracyjnymi prowadzono na Pojezierzu Olsztyńskim w latach 1994-2007. Do badań wytypowano zlewnie: rolniczą odwadnianą siecią drenarską, rolniczo-leśną odwadnianą siecią rowów i drenów oraz rolniczą o dużym udziale obszarów leśnych (ok. 30%), odwadnianą rowami melioracyjnymi. Odpływ wód z urządzeń melioracyjnych mierzono co dwa tygodnie, a raz na miesiąc w wodzie oznaczano N-NO_3, N-NO_2, N-NH_4 oraz azot metodą Kjeldahla. Wykazano, że o wielkości odpływu wody systemami melioracyjnymi decydują głównie ilość i rozkład opadów atmosferycznych, a szczególnie ich ilość w półroczu zimowym. Dynamika stężeń i ładunków azotu w wodach odpływających systemami odwadniającymi była zmienna w czasie i zależała nie tylko od ilości i rozkładu opadów w roku i wieloleciu, ale również od sposobu zagospodarowania zlewni i systemu odprowadzającego wodę. Stwierdzono, że intensywne opady w sezonie letnim zwiększają odpływ wody w niewielkim stopniu, i tylko w przypadku sieci drenarskiej. Ładunek azotu ogólnego odpływającego systemami melioracyjnymi ze zlewni rolniczych jest ściśle uzależniony od ilości odpływającej wody oraz od stężenia w niej mineralnych związków azotu, szczególnie N-NO_3. Największe straty azotu z terenów zmeliorowanych występowały w okresie wiosennym, co wiąże się z sezonowym odpływem wód i jego kulminacją w miesiącach marzec-kwiecień. Największe stężenie azotu ogólnego (16,69 $mg \cdot dm^{-3}$) występowało w wodach odpływających siecią rowów i drenów, ale ze względu na intensywniejsze odwodnienie gleb większy jego ładunek, średnio o 33%, odpływał drenami. Z 1 ha zlewni rolniczej drenami odpływało do 13,13 kg azotu ogólnego rocznie, w tym do 12,04 kg azotu mineralnego.

Słowa kluczowe: azot, dreny, rowy, zlewnia rolnicza, systemy odwadniające.

INTRODUCTION

Threats posed by man's activity to the environmental quality of rural areas are a consequence of a combination of many natural and anthropogenic factors. Among the major man-made stress factors, which can be controlled and modified, are the type of land use in a catchment basin, including the share and location of arable lands, permanent grassland, forests, peatbogs and wetlands, water pools, tree assemblages and thickets, as well as the intensity of agricultural practice, including the amounts and forms of fertilizers (ALLAN, CHAPMAN 2001, HERZOG et al. 2008, GRABIŃSKA et al. 2005, HEATHWAITE et al. 1998, OENEMA et al. 2005, SPRUILL 2004). More intensive farming, often resulting in turning more grounds into arable land, has long been inseparebly connected with the development of draining systems, the aim of which in Poland is mainly to accelerate water outflow (LIPIŃSKI 2002). Thus, draining does not usually affect much groundwater, but just carries away excess of precipitation (LIPIŃSKI 2003). However, the fact that water shortages, which may appear following a prolonged after-drought period, cannot be replenished raises the risk of inferior crop yields and initiates many soil processes, especially mineralization of organic matter. Excessive quantities of released nutrients, due to the limited access to water, do not undergo biosorption, which means they are more likely to be leached by rainfall into deeper layers of the soil profile. They enter groundwater, and through drainage systems, quickly travel to surface waters, where they can cause eutrophication and pollution (KOC et al. 2007, SZYMCZYK, SZYPEREK 2005, SZYMCZYK et al. 2005, VAGSTAD et al. 2000). The dependence of the outflow of water through drainage ditches on atmospheric precipitation is very complex, being shaped by such elements as the amount and time distribution of precipitation, structure and permeability of a soil profile, level of groundwater, influx water supply, temperature and species of crops (LIPIŃSKI 2002, SZYMCZYK, SZYPEREK 2005). Precipitation water contains elements which are already dissolved, and this facilitates their migration within the environment and participation in physicochemical processes of ion exchange in soil. During intensive rainfall, the nitrogen contained in rainfall water quickly migrates to groundwater, and with the surface and subsurface flow, enters surface water (LIPIŃSKI 2002). Large changeability in the concentration of nitrogen in water and the outflow of nitrogen load through draining systems is connected with both the type of a draining system and the intensity of farming practice in a given agricultural catchment basin (KOC et al. 2007, KOPACZ et al. 2007, PULIKOWSKI et al. 2008, SZYMCZYK, SZYPEREK 2005). The outflow of nitrogen load from agricultural basins can be drastically limited by such structural, spatial and economic transformations that lead to changes in land use. As a result of such modifications, the area of farmed land decreases (more idle and fallow land) or some farmland is transformed so as to sustain low-cost, organic farming (KOPACZ et al. 2007).

The objective of this study has been to determine the dynamics of concentrations and loads of nitrogen carried away from basins which differed in the type of land use, soil compactness and draining system. The analysis was performed on the backdrop of changing meteorological conditions in the multi-year period from 1994 to 2007.

MATERIAL AND METHODS

In 1994-2007, a study was carried out in Olsztyn Lake District (Pojezierze Olsztyńskie) on the dynamics of nitrogen outflow from agricultural areas, with water drained by different types of draining systems. Three basins, which differed in the land use, soil compactness and draining systems, were selected for the study. The first basin was an agricultural one; it covered 34 ha (arable lands – 98%) and was drained with a drainage system. The prevailing soils were medium-compact and light ones, developed from sandy, loamy and silty formations. The second basin was agricultural and forested in character. It covered about 250 ha and was drained with an irregular network of drains and open ditches. The predominant form of land use (over 60%) was arable land, while about 34% of the total area was covered by forests and field tree assemblages. The basin comprised light and very light soils developed from sands, with some loams and silty, sandy or loamy formations. The third basin, which covered over 280 ha, was drained with an irregular network of drainage ditches. About 50% of the basin's area was covered by arable land, 15% belonged to grasslands (since 1993 some set aside) and about 30% was overgrown with forests and trees. The soils in this basin were mainly medium-compact and light ones, developed from medium loams and loamy sands. A small area of the basin lies on silty soils and peat. Later in this paper, the three basins are characterised according to the type of a draining system.

The flow of water in draining facilities was measured at two-week intervals, and once a month water samples were taken for the following determinations: nitrate nitrogen (V) – $N\text{-}NO_3$, by colorimetry with disulfofenolic acid; nitrate nitrogen (III), by colorimetry with sulfanilic acid; ammonia nitrogen – $N\text{-}NH_4$, by colorimetry with Nessler's reagent and Kjldahl nitrogen – N_{Kj} (ammonia nitrogen + organic nitrogen) by distillation after mineralization in sulfuric acid. The following concentrations were calculated for the analyzed water samples: mineral nitrogen (N_{min}) from the formula [N_{min} = $N\text{-}NH_4$ + $N\text{-}NO_3$ + $N\text{-}NO_2$] and total nitrogen (N_{og}) – [N_{og} = $N\text{-}NH_4$ + + $N\text{-}NO_3$ + $N\text{-}NO_2$ + N_{org}}. Based on the measured flows, first a monthly outflow of water was calculated, and then loads of the determined forms of nitrogen. The results were processed statistically using *Statistica 8PL* software, generating the following values: linear (Pearson's) correlation coefficients (*r* Pearson's), normal distribution of data using Shapiro-Wilk test, a $p \leq 0.05$ and statistically homogenous groups using Kruskal-Wallis test.

RESULTS AND DISCUSSION

In the hydrological years 1994-2007, the total annual precipitation in the environs of Olsztyn ranged from 408 mm (1996) to 827 mm (2007) – Figure 1. Compared to the multi-year period 1951-2000 (average 616 mm), half of the analyzed 14-year period (7 years) had moderate/normal (±10%) rainfall; the other years could be classified as: one very dry year (1996), 3 dry years (1998, 2003 and 2005) and 3 humid years (1995, 2004 and 2007).

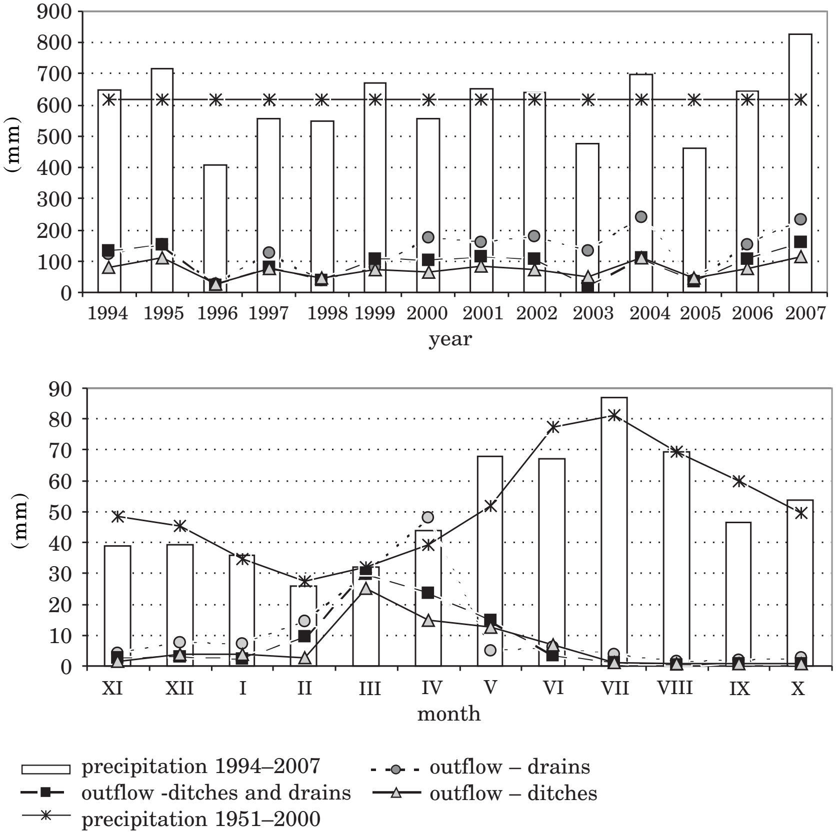

Fig. 1. Dynamics of the annual and monthly water discharge through draining systems from agricultural areas against the background of atmospheric precipitation in 1994-2007 (mm)

The monthly total rainfall was characterized by large variability over time (Figure 1). On average, during the 14-year period, the driest month was February (average precipitation 26 mm) and the wettest was July (86 mm). With respect to the multi-year period covered by this study, demonstrably less rainfall occurred in November (on average, by 9 mm less), December (by 6 mm), June (by 10 mm) and September (by 13 mm), and more rainfall appeared in April (on average by 5 mm more), May (by 16 mm), July (by 6 mm) and October (by 4 mm). In respect of the total precipitation, the analyzed period was dominated by normal (40%) and dry months (18%). Compared to an analogous multi-year period (1951-2000), in the winter half-years of the analyzed period the precipitation was lower by 11 mm (Table 1). The lowest precipitation in this half-year occurred in 1996 (on average, 104 mm) and the highest was recorded in 1994 (on average 335 mm). In the summer half-year, the atmospheric precipitation was on average 3 mm

Table 1

Discharge of water through the analysed draining systems in the winter and summer hydrological half-years versus the meteorological conditions

Year	Average temperature (°C)			Precipitation (mm)		Outflow of water (mm) drains		Outflow of water (mm) drains and ditches		Outflow of water (mm) ditches	
	XI-X	XI-IV	V-X	XI-IV	V-X	XI-IV	V-X	XI-IV	V-X	XI-IV	V-X
1994	8.6	2.1	15.1	335	314	113	10	126	8	53	28
1995	8.2	0.9	15.5	274	443	115	38	137	15	77	35
1996	5.8	-1.9	13.4	104	305	21	6	10	14	12	16
1997	7.3	0.6	13.9	136	420	102	22	69	12	43	35
1998	7.3	1.0	13.5	197	353	31	9	30	9	22	25
1999	8.2	1.8	14.5	269	403	45	35	89	18	49	24
2000	8.6	3.2	14.0	208	350	144	32	85	17	59	6
2001	7.4	0.5	14.4	202	451	128	32	93	20	69	15
2002	8.4	1.6	15.1	224	417	158	23	80	26	56	18
2003	7.5	0.9	14.1	119	359	127	5	13	7	27	23
2004	7.3	1.1	13.6	255	441	213	26	59	52	38	72
2005	8.3	1.5	15.2	196	264	26	11	25	10	40	5
2006	7.9	0.4	15.4	193	452	124	29	43	63	68	9
2007	8.5	2.5	14.6	316	511	215	18	131	29	110	6
Average	7.8	1.2	14.4	216	392	112	21	71	21	51	23
1951-2000	7.1	2.1	12.1	227	389						

higher than in a comparable half-year from the 1951-2000 multi-year period. The rainfall was characterized by a very large amplitude, from 264 mm in 2005 to 511 mm in 2007.

In general, the examined multi-year period was warmer (by 0.7°C) than the 1051-2000 period, although it had colder winter half-years (on average by 0.9°C), but warmer (on average by 2.3°C) summer half-years (Table 1).

The amount and distribution of atmospheric precipitation in the particular years and time periods analyzed had a considerable influence on the volume of water carried away through the draining systems, although the effect was found to be significant only for the winter half-year (Table 1, Figure 2). In the 14-year period (1994-2007), the annual water outflow ranged from 20 mm (mixed system, 2003, dry year) to 239 mm (drains, 2004, wet year). Regarding the volume of water carried away from the basin, the drainage systems should be ordered as follows: drains (on average 133 mm) > ditches and drains (on average 92 mm) > ditches (on average 74 mm).

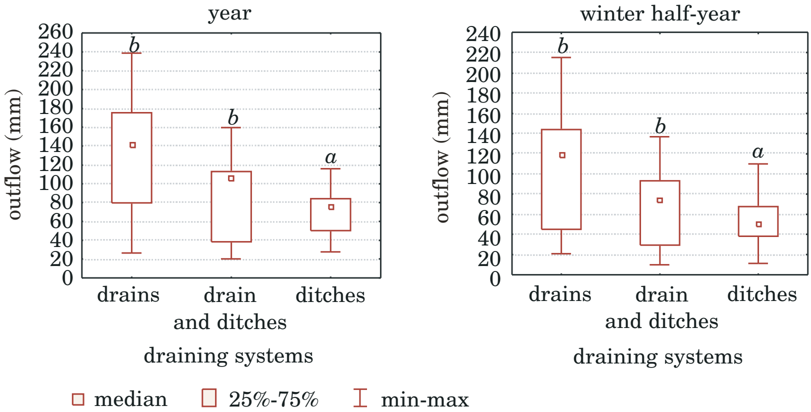

Fig. 2. The influence of the draining systems on the volume of discharged water

The smallest outflow of water, less than 50 mm, appeared during dry years, when a very small portion of the rainfall (4-10%) was carried away with the draining systems. The outflow of water was particularly strongly reduced in the summer half-year despite relatively high precipitation occurring at that time. This suggests that most of the rainfall underwent evapotranspiration. Most of the precipitation (up to 34%), in turn, was carried away from the basins during the wet years. A clear tendency appeared for a larger outflow in the basins drained with the drainage system (21-34%0 than with the mixed system (16-21%) or with ditches alone (14-16%).

Our study has demonstrated that the water outflow through draining systems grows considerably in winter, reaching the peak value in spring (Figure 3).

It has also been found that more intensive water draining through the drainage system compared to the ditches or the mixed system can result in a rapid increase in the water outflow, so that the amount of water discharged can exceed the current rainfall.

The discharge of water through the drainage system was higher than the one recorded for the mixed network or through the ditches. However, the statistical analysis proved that it was significantly higher only in summer versus the system of drains and ditches and in autumn and winter compared to the system of ditches (Figure 4).

In the analyzed multi-year period, this tendency featured particularly strongly in the spring in 2003, 2004 and 2007, when the amount of water discharged through the drainage system was higher than the current rainfall. This was caused by a larger – compared to the basins drained with the mixed system or with the ditches – share of more compact soils, which were almost totally (98%) used as arable lands. With the higher retention of these soils, more water was accumulated in the soil profile during autumn and winter and more was discharged in spring. This tendency con-

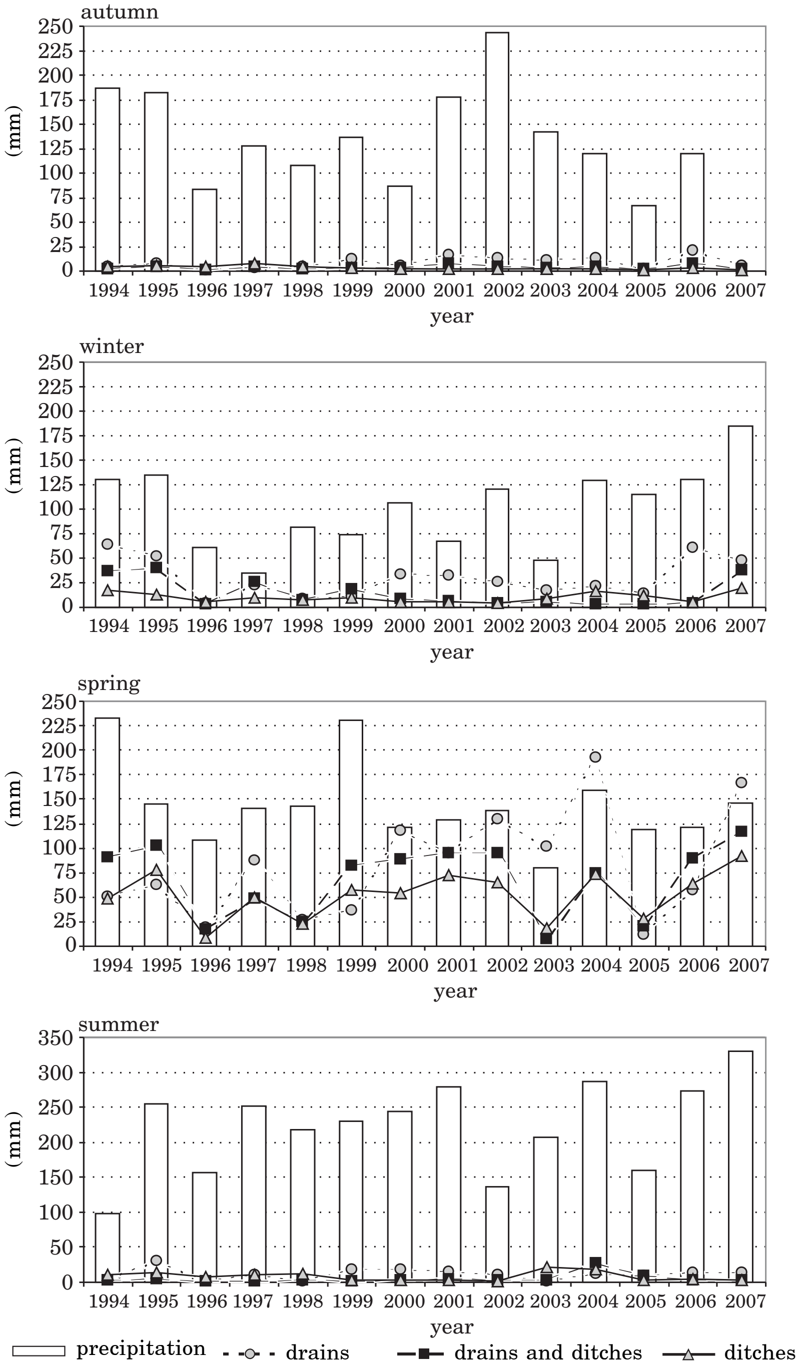

Fig. 3. Dynamics of the seasonal water discharge from agricultural areas though draining systems versus against the background of atmospheric precipitation in 1994-2007 (mm)

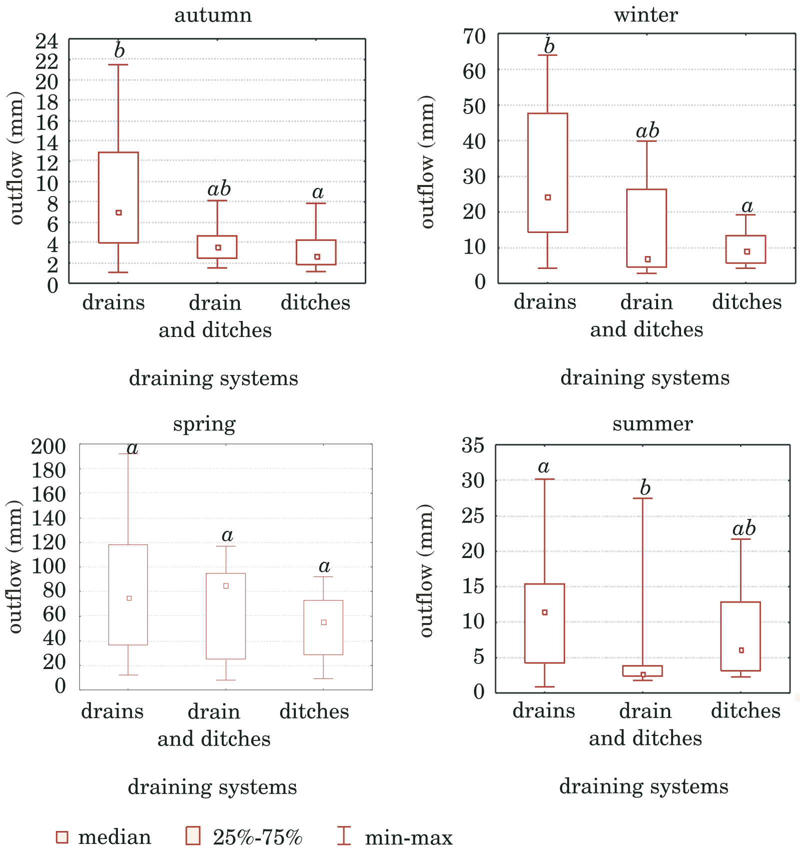

Fig. 4. The influence of a draining system on the seasonal dynamics of water discharge from an agricultural basin

firms how important is the role of forests and thickets present in the other two basins (34 and 30%) in regulating and maintaining an equilibrium of the annual water outflow. It was only in the autumn and summer that the examined draining systems discharged similar amounts of water and demonstrated a similar response to the volume and distribution of atmospheric precipitation. This finding supports the claim that the relationship between water discharge and rainfall is a very complicated one and depends on a number of factors, which condition the intensity of water migration in the environment (LIPIŃSKI 2002).

The content and outflow of nitrogen with the systems which drained the agricultural basins varied over a wide range and depended on both the type and intensity of land use, type of a draining system and meteorological conditions, which influenced the amount and intensity of translocation of water, and that also meant translocation of water-dissolved elements within the enviornment. Depending on such factors present in the three agriculturally used catchment basins, which differed in the extent of man-made stress as well as the type of a water draining system, the amount of total nitrogen varied from 0.16 to 16.69 mg dm^{-3}, and its annual outflow was 0.36 to 13.13 kg ha^{-1} (Table 2).

Most of the nitrogen in water was mineral nitrogen (up to 97%), of which the dominant form was N-NO_3. This confirms the assumption that one of the major factors affecting the intentsity of eutrophication and quality of water is the leaching of N-NO_3 from soils (KOC et al. 2009).

The highest variations in the concentration of nitrogen (0.43-16.69 mg dm^{-3}) as well as higher levels of nitrogen (on average 4.68 mg dm^{-3}) were found in water drained through a draining system which consisted of drains and ditches. This was associated with the fact that this catchment basin

Table 2

Extreme values and mean concentrations and loads of nitrogen in water discharged from agricultural basins

Draining systems	Form of nitrogen	Min.	Max.	Average	Median	*V* (%)
Concentration (mg·dm^{-3})						
Drains	N-NO_3	0.08	9.67	2.72	2.67	41
	mineral N	0.14	10.22	3.21	2.95	34
	total N	0.16	10.53	3.56	3.24	33
Drains and ditches	N-NO_3	0.16	11.97	3.46	3.57	23
	mineral N	0.38	15.03	4.11	3.99	26
	total N	0.43	16.69	4.68	4.60	25
Ditches	N-NO_3	0.02	0.85	0.53	0.46	38
	mineral N	0.60	1.60	0.93	0.91	29
	total N	0.71	1.90	1.09	1.08	30
Load (kg·ha^{-1})						
Drains	N-NO_3	1.13	11.66	5.02	4.28	60
	mineral N	1.44	12.04	5.45	4.81	59
	total N	1.60	13.13	5.98	5.28	58
Drains and ditches	N-NO_3	0.78	7.35	3.27	2.70	62
	mineral N	0.83	8.89	3.70	3.12	61
	total N	0.94	9.81	3.99	3.55	60
Ditches	N-NO_3	0.08	1.51	0.51	0.31	87
	mineral N	0.31	1.78	0.75	0.60	60
	total N	0.36	2.08	0.87	0.70	60

V – coefficient of variation

comprised more light soils compared to the area drained only with drains. However, a more intensive water dewatering of drained soils, irrespective of a lower nitrogen concentration (on average 3.56 mg dm^{-3}), resulted in a larger (by 50%) load of discharged total nitrogen. Lower concentrations and the smallest outflow of total nitrogen as well as its main fractions (especially N-NO_3) occurred in water carried away through ditches. This was connected with the less intensive use of the basin and a relatively small, versus the drains, outflow of water.

The dynamics of the concentrations of mineral nitrogen compounds in water carried away by the analyzed systems varied with time and depended not only on the amount and distribution of rainfall during a year and in

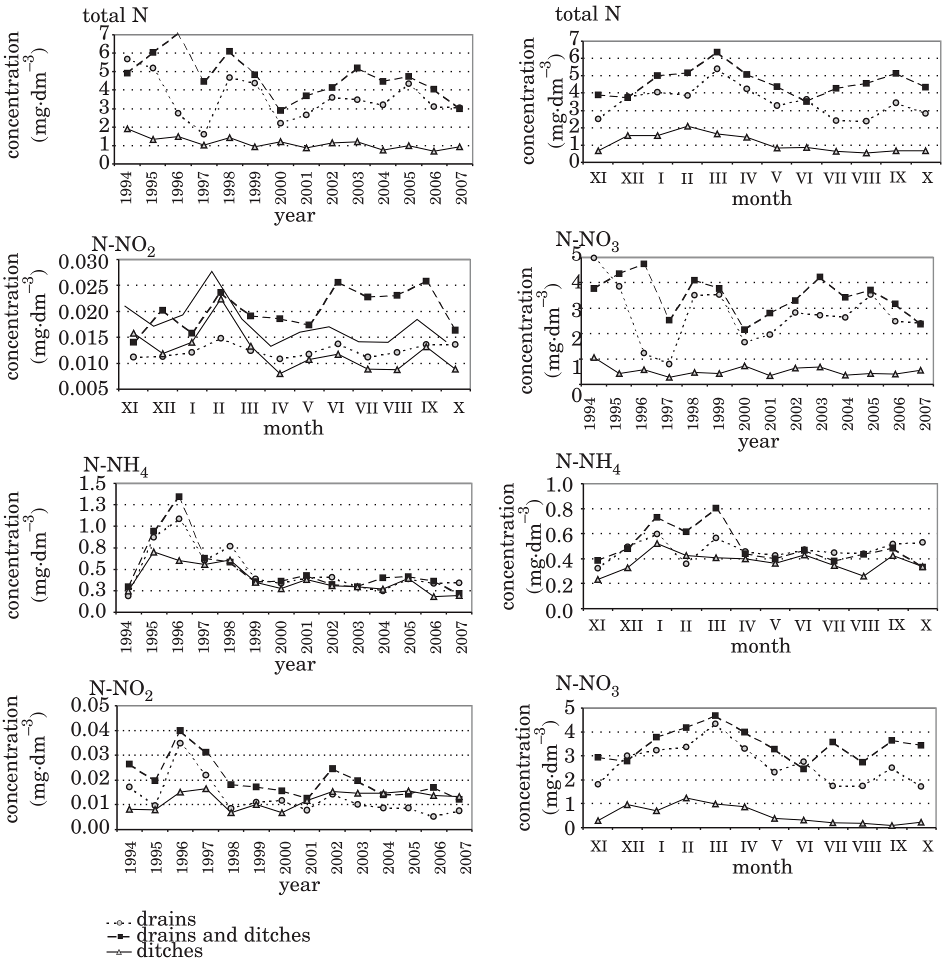

Fig. 5. Dynamics of the annual and monthly nitrogen concentrations in water discharged from agricultural areas in 1994-2007 (mg dm^{-3})

the multi-year period, but also on the land use in a given catchment basin and its draining system (Figure 5).

The smallest variability in the concentration, especially for $N\text{-}NO_3$, which made up the dominant part of mineral nitrogen, appeared in water drained through ditches with a supplementary network of drains. In the water discharged through ditches and drains, $N\text{-}NO_3$ made up 88% of mineral nitrogen and 81% of total nitrogen, and in the water discharged through drains, it constituted 68% of mineral N and 59% of total N. This finding suggests that the leaching of nitrogen from soil takes place after mineralization of organic nitrogen and oxidation to $N\text{-}NO_3$. This is a consequence of the fact that draining facilitates oxygen supply to a soil profile, which induces a series of soil processes, for example it raises the intentity of mineralization of organic substances (LIPIŃSKI 2002). Thus, improved oxigenation of drained soils under agricultural use may be a cause of an increased threat of water becoming polluted with nitrogen compounds, especially during a more intensive water draining of soils than recorded in draining systems comprising or consisting of cditches. Therefore, for the sake of environment conservation, the existing or planned drainig systems should be equipped with facilities which will regulate water discharge (LIPIŃSKI 2002).

The present study has not demonstrated any significant influence of the type of a draining system on the concentration of $N\text{-}NH_4$ in the analyzed water samples. In the water discharged through drains, compared to the samples taken from ditches, an elevated concentration of $N\text{-}NO_3$ appeared alongside levels of mineral N and total N (associated with this parameter) as well as $N\text{-}NO_2$, compared with the mixed system (drains and ditches – Figure 6).

A relatively high concentration of $N\text{-}NH_4$ was found in 1996, which was the driest year during the 14-year period. The highest levels of this nitrogen form, unseen in the other years, were determined then in water discharged through the drainage system (on average 1.09 mg dm^{-3}) and from the mixed system (on average 1.34 mg dm^{-3}). Over 20% higher concentration of $N\text{-}NH^4$ in water discharged through the mixed system may have been caused by a more intensive decomposition of organic matter at the bottom of ditches, where periodically oxygen deficiency can occur and the decomposition of organic substance slows down and is limited to ammonification. Similar relationships have been observed for $N\text{-}NO_2$. Small concentrations of $N\text{-}NO_2$, relative to $N\text{-}NO_3$, which occurred especially in water carried away through the drainage system, confirm good oxygenation of the soils drained with this system. The highest $N\text{-}NH_4$ level in the water drained through ditches (on average 0.70 mg dm^{-3}) was found in 1995, a wet year, characterized by a relatively large discharge of water, including nutrients, during the early vegetative growth period.

The dominant share of $N\text{-}NO_3$ in total nitrogen in water discharged through draining systems confirms that its variability runs a similar course to the variability of total nitrogen in all seasons of the year (Figure 7). The

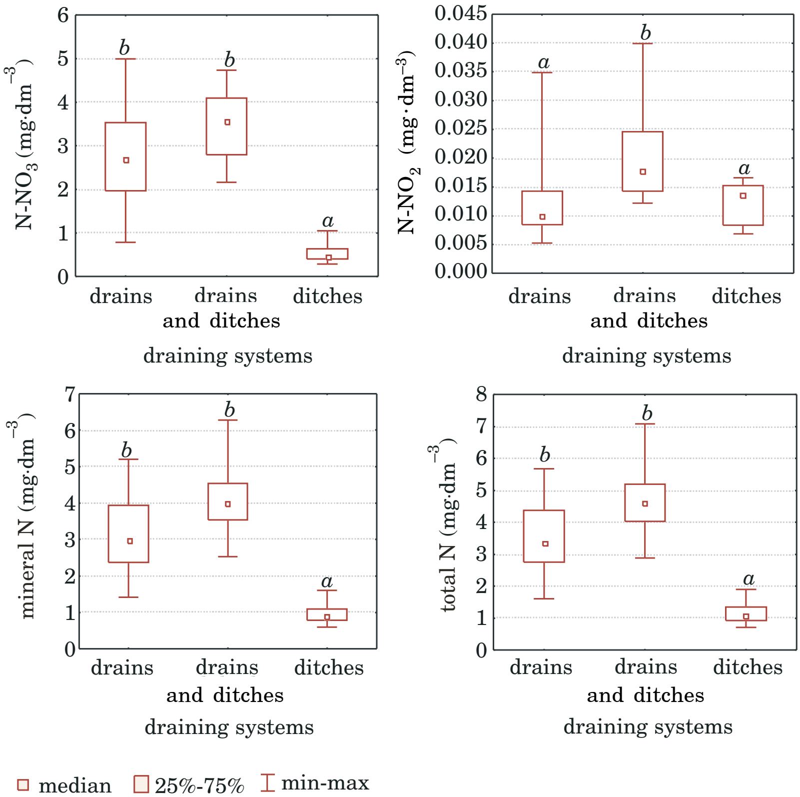

Fig. 6. Dynamics of concentrations of nitrogen compounds in water discharged from agricultural areas

highest concentrations of total nitrogen and N-NO_3 in water discharged through the drainage system or ditches with drains (the mixed system) appeared in spring, while in the ditches alone, the highest levels of these nitrogen forms were recorded in winter.

With respect of ammonia and nitrate (III) nitrogen, variations in the levels of these nitrogen forms followed a slightly different course. Nonetheless, because of their small concentrations, as compared to the levels of N-NO_3, they did not produce any significant effect on the variation of total nitrogen concentrations in water.

The correlation dependences between meteorological conditions (temperature and precipitation) and volume of discharged water demonstrated that the effect they produced on the concentration and load of discharged nitrogen depended on the type of a draining system (Table 3). Negative correlations between temperature and the concentration and load of nitrogen suggest that during the plant growing season (rising air temperature) the amount of nitrogen discharged from drained agricultural basins decreases,

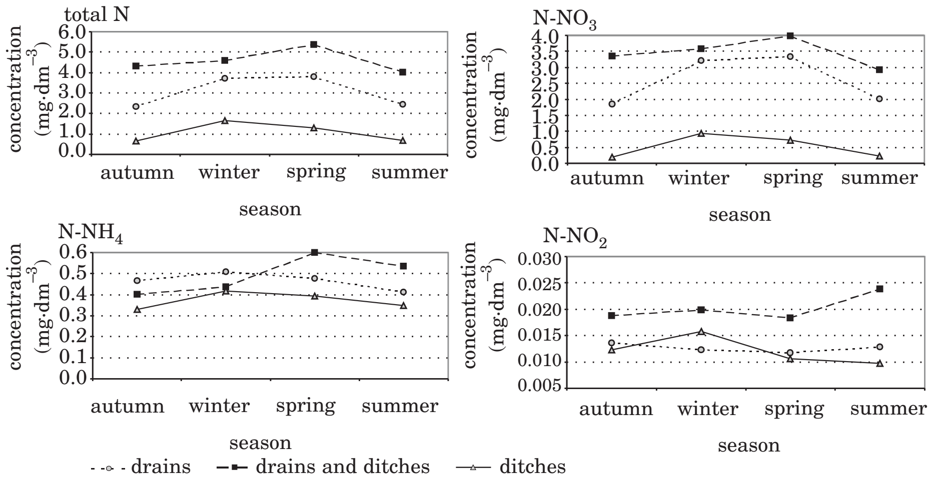

Fig. 7. Seasonal dynamics of nitrogen concentrations in water discharged from agricultural areas in 1994-2007 (mg dm^{-3})

which is a result of nitrogen bioaccumulation. This dependence became particularly evident when soils were drained with the drainage system or with the ditches.

Similar tendecies were also determined for atmospheric precipitation, most of which fell during summer (Table 3). Also, a tendency was demonstrated for the lowering of N-NH_4 and N-NO_3 in water and increased discharge of these forms of nitrogen through the analyzed draining systems.

A positive correlation has been demonstrated between the concentration of N-NO_3, which represented the major portion of nitrogen contained in water, and the volume of discharged water. This led to a significant increase in the load of N-NO_3 and, consequently, mineral and total nitrogen. Such findings are confirmed by the results reported by PULIKOWSKI et al. (2008), who demonstrated that a larger load of nitrogen is discharged from drained basins mostly under agricultural land use, which was mainly attributed to a high concentration of nitrates in the drainage effluent.

The volume of nitrogen load discharged with the draining systems from the agricultural basins during the whole analyzed period as well as in individual years was mainly conditioned by the amount of discharged water, its flow rate and concentration of N-NO_3 (Figure 8). The most important was the water discharge in winter half-year (from October to April, Figure 2), i.e. during the time when water supplies in a basin are replenished (from November to February), as implied by a relatively small water outflow versus precipitation. The largest water outflow occurred during its annual culmination, mainly in March and April (Figure 1).

Thus, particularly large loads of N-NO_3, and consequently total nitrogen, appear in March and April in the basin drained with the drainage sys-

Table 3

Correlations between temperature. precipitation and water outflow versus concentration and load of nitrogen in water from draining systems (at $p < 0.05$; $N = 150$)

Variable	Temperature			Precipitation			Load		
	drains	drains and ditches	ditches	drains	drains and ditches	ditches	drains	drains and ditches	ditches
Concentration									
N-NO_3	-0.18*	–	-0.40*	–	-0.18*	-0.22*	–	–	0.17*
N-NH_4	–	-0.26*	–	–	-0.16*	–	–	–	–
N-NO_2	–	–	-0.20*	–	–	–	–	–	–
Load									
N-NO_3	-0.21*	–	–	–	–	–	0.70*	0.77*	0.57*
N-NH_4	-0.18*	–	–	–	–	–	0.59*	0.67*	0.74*
N-NO_2	-0.18*	–	–	–	–	–	0.74*	0.76*	0.30*
Mineral N	-0.22*	–	-0.17*	–	–	–	0.72*	0.81*	0.66*
Total N	–	–	-0.18*	–	–	–	0.72*	0.82*	0.66*

*essential correlation; (–) lack of essential dependences

tem, and in March in the basins drained with the mixed system or with the ditches (Figure 8).

Much larger water discharge and water levels of nitrogen compounds meant that a significantly larger nitrogen load (except N-NO_2) was discharged by the drainage and mixed systems than through the ditches (Figure 9).

The present study has also demonstrated that much more N-NH_4 is discharged through draining ditches in years characterized by a more even annual water discharge. Possible sources of N-NH_4 include atmospheric precipitation polluted with ammonia (LIPIŃSKI 2002), which directly feed surface waters, or its supply from surface effluents, especially in spring. In the summer season, in turn, much N-NH_4 reaches a basin after intensive rains. An additional source of N-NH_4 in water drained through ditches could be the products of decomposition of organic matter derived from dying plants and bottom sediments. This can be associated with the release of this form of nitrogen from plants and bottom sediments.

The load of nitrogen discharged through the draining systems (Figure 8) was closely connected with the seasonality of water flow (Figure 1, Table 1). Consequently, the highest loads of total and of the determined mineral nitrogen forms were the highest in the spring and the lowest in the autumn and winter. In respect of total nitrogen in spring, the largest loads were dsicharged through drains (4.0 kg ha^{-1}), followed by the network of ditches

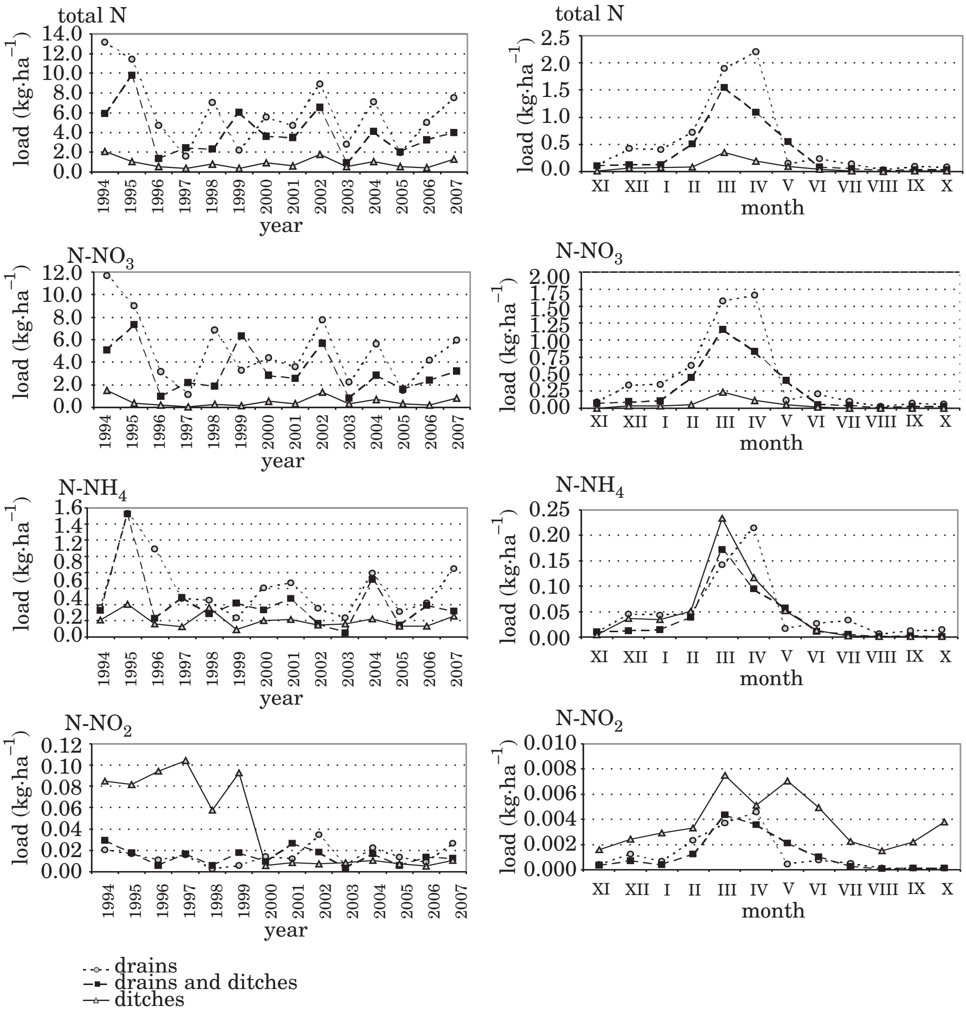

Fig. 8. Dynamics of annual and monthly outflow of nitrogen through draining systems in agricultural areas in 1994-2007

and drains (3.0 kg ha^{-1}) and the smallest ones – through ditches (0.6 kg ha^{-1}) – Figure 10.

Similar tendencies were observed for the outflow of loads of N-NO_3 (3.23 kg ha^{-1} through drains > 2.40 kg ha^{-1} through ditches and drains > 0.38 kg ha^{-1} through ditches) and N-NH_4 (0.37 kg ha^{-1} through drains > 0.32 kg ha^{-1} ditches and drains > 0.12 kg ha^{-1} through ditches). As for N-NO_2, an over two-fold larger load of this form of nitrogen was discharged through ditches than through drains or ditches and drains. The smallest discharge of N-NO_2 occurring in the spring in the basin drained with the

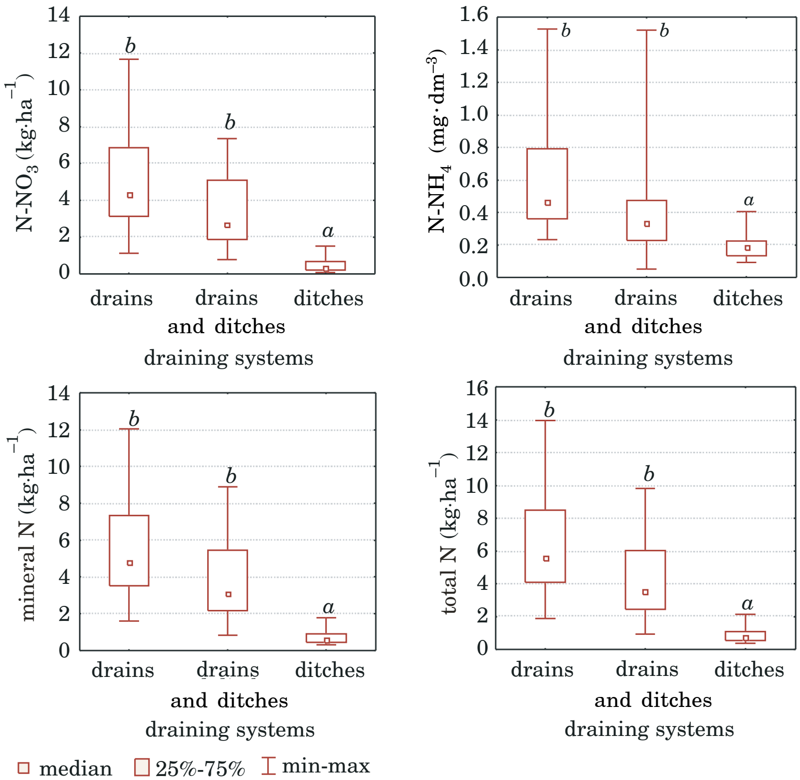

Fig. 9. Dynamics of loads of nitrogen compounds in water discharged from agricultural areas

drainage system should be associated with a much more rapid water outflow and better oxygenation of drained soils as compared to soils dewatered with ditches (Koc et al. 2009). This was also confirmed by the seasonal dynamics of the load of N-NO_3.

The statistical analysis verified the predominant influence of meteorological conditions, mainly atmospheric precipitation and air temperature (significant seasonal variability) on the volume of the outflow of forms of nitrogen through the draining systems dewatering agricultural basins (Figures 11-13). Significantly higher nitrogen loads, than in autumn, were discharged in spring. However, the seasonal dynamics of the outflow of particular forms of nitrogen was found to differ slightly between the three tested draining systems. In the case of the drainage systemn and the network of ditches, significantly larger loads of nitrogen compounds were discharged in spring.

The results of our tests have demonstrated that the discharge of nitrogen compounds from agricultural areas is largely dependent on the meteor-

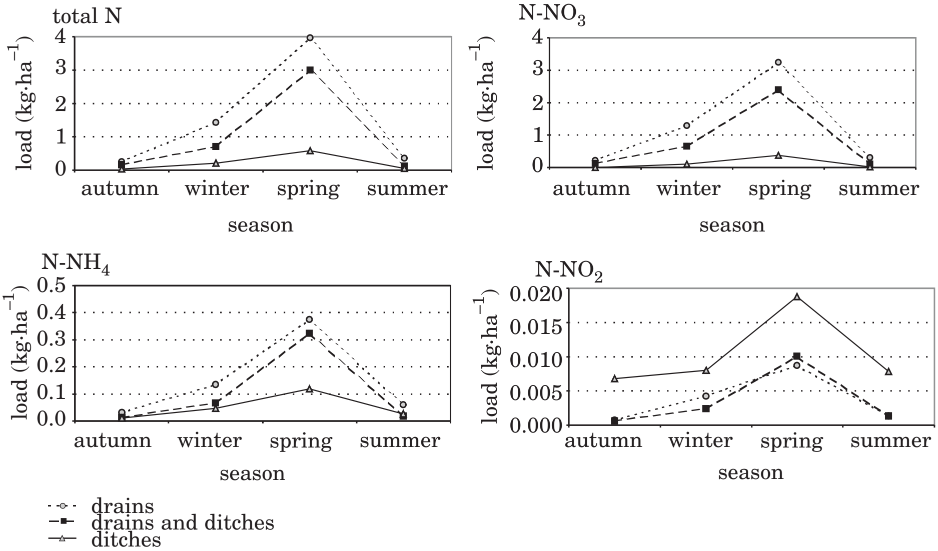

Fig. 10. Seasonal dynamics of nitrogen outflow through draining systems in 1994-2007 (kg ha^{-1})

ological conditions, draining system ,type of soils and type of lanbd use. At the same time, they seem to confirm the claim that the influence of agriculture on chemism of groundwater and surface water can be both positive and negative, and the amount of pollutants originating from area sources can be considerably reduced by proper water management (HEATHWAITE et al. 1998, HERZOG et al. 2008, OENEMA 2005). This can be achieved by reducing the intensity of fertilization and limiting surface area of cropped land (KOPACZ et al. 2007) because, particularly in spring, during the intensive growth and development of plants, bioaccumulation of nitrates exceeds the sum of nitrates reaching a bsinc from the atmosphere and originating from mineralization and nitrofication of organic compounds of nitrogen in soil (KOWALIK, KULBIK 2002).

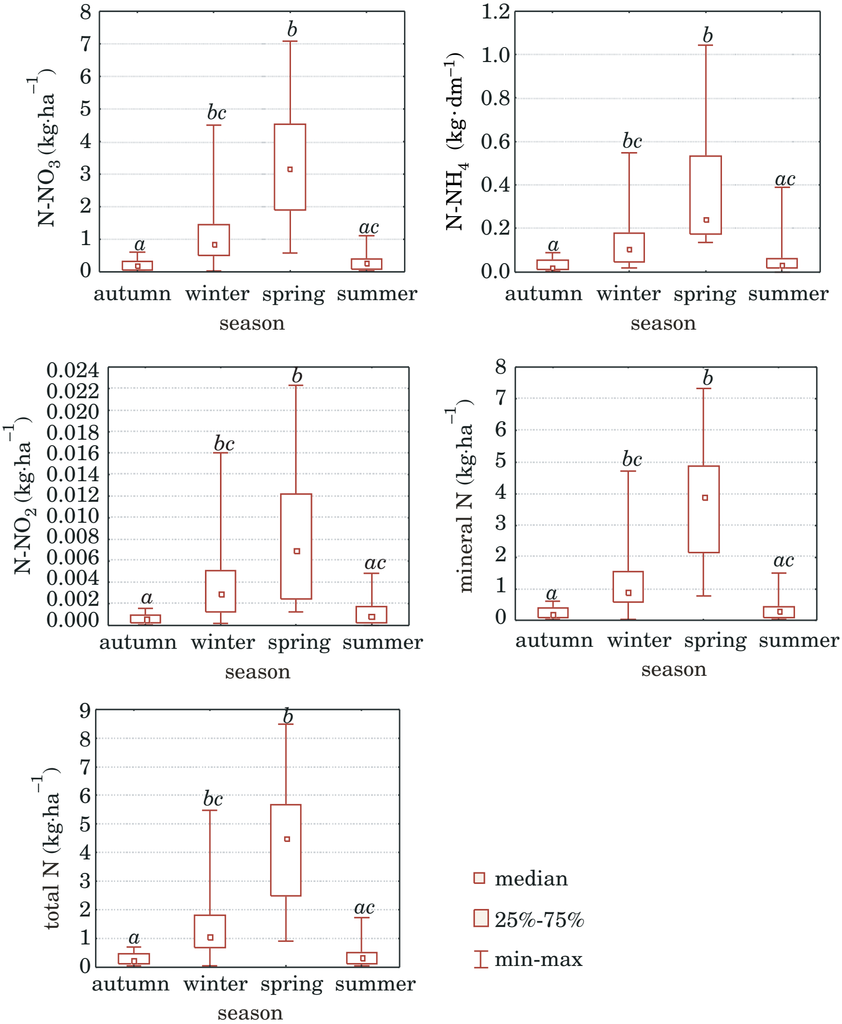

Fig. 11. Seasonal dynamics of loads of nitrogen in water discharged through a drainage system

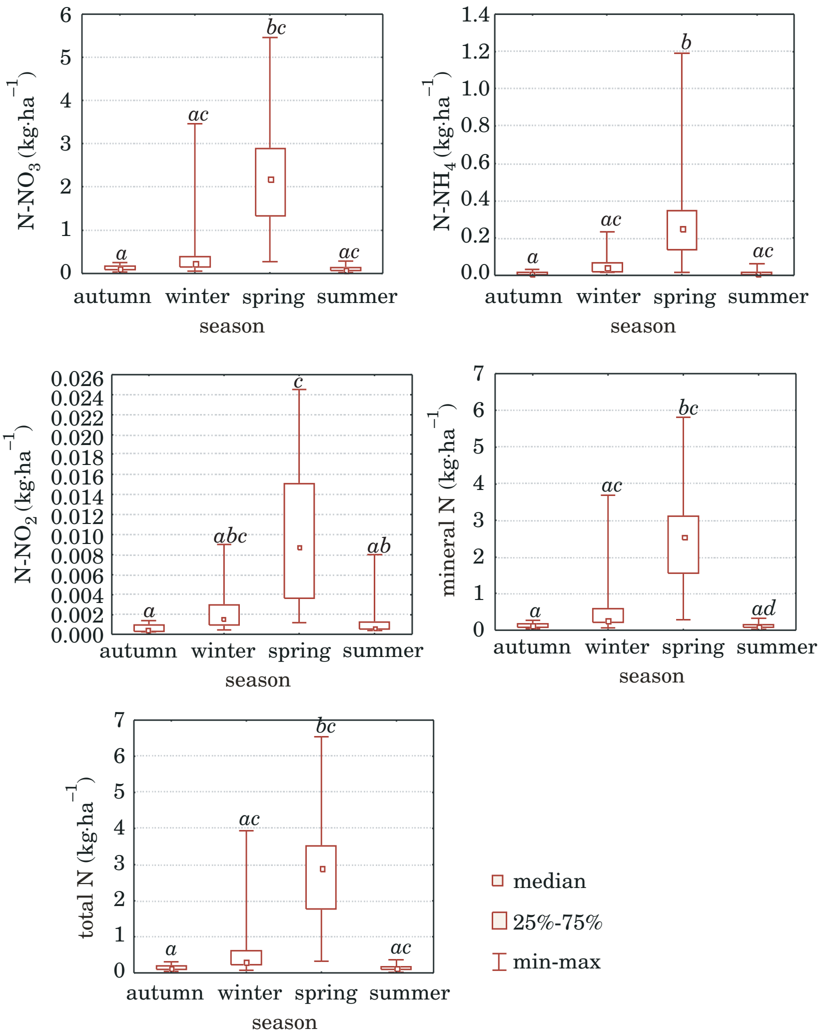

Fig. 12. Seasonal dynamics of loads of nitrogen in water discharged through a network of ditches and drains

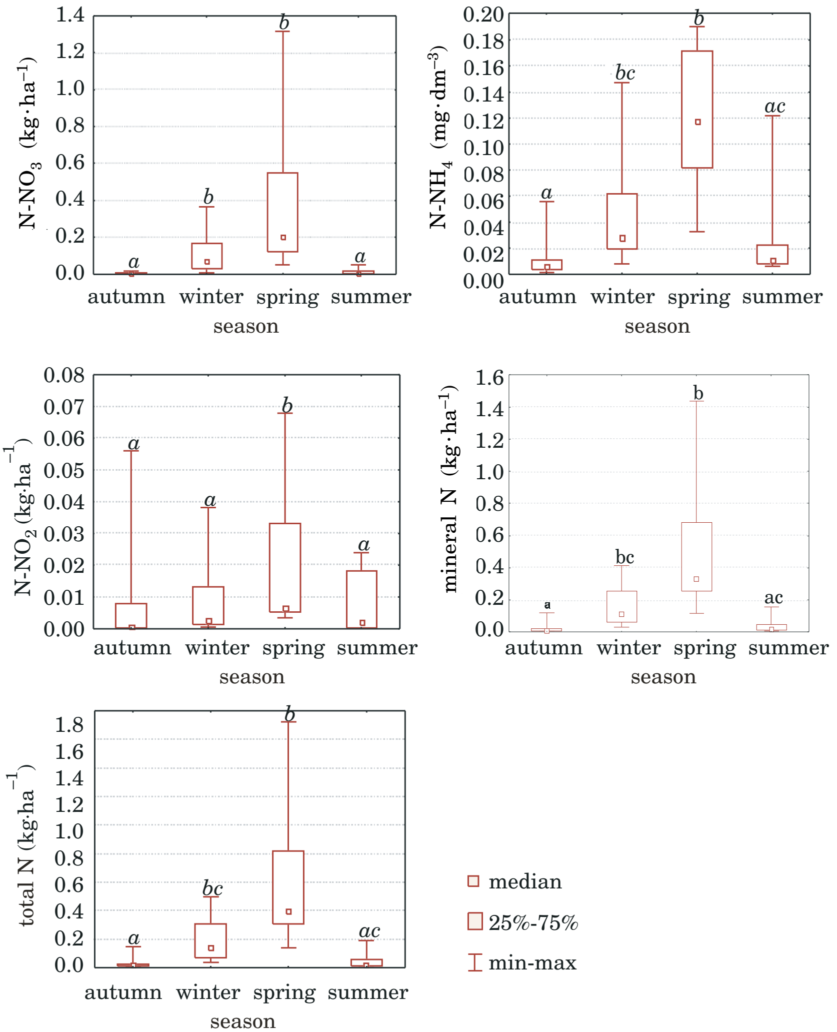

Fig. 13. Seasonal dynamics of loads of nitrogen in water discharged through draining ditches

CONCLUSIONS

1. The dynamics of water discharge from an agricultural basin depended on the amount and distribution of atmospheric precipitation as well as the type of a dewatering system, adjusted to the type of soils and type of land use. The volume of discharged water was mainly conditioned by atmospher-

ic precipitation in the winter half-year. Intensive rainfall occurring in summer would only slightly increase the outflow of water from the baic drained with a drainage system.

2. The dynamics of concentrations and loads of nitrogen in water discharged via draining systems varied with time and depended not only on the amount and distribution of precipitation over a year and in the multiyear period, but also on the type of land use in a given basin and a draining system. The largest variation in the concentrations of N-NO_3 (V=41%) and total nitrogen (V=33%) appeared in water drained with the drainage system, and the largest variation in the loads (N-NO_3 – V=87%, and total N – V=60%) was calculated for water carried away through draining ditches.

3. The largest concentration of total nitrogen (16.69 mg dm^{-3}) occurred in water carried away through the mixed system, and the lowest one – in water discharged through ditches. Within total nitrogen, mineral nitrogen reached from 84% in water flowing through ditches to 97% in water from drains. Within mineral nitrogen, the percentage of nitrates (V) ranged from 53% in water flowing through ditches to 95% in water from drains.

4. The annual outflow of total nitrogen per 1 ha was the highest from the agricultural basin dewatered by the drainage system, where it reached 13.13 kg. When it was dewatered through drains and ditches, the annual outflow of total nitrogen was 9.81 kg, falling down to 2.08 kg in the case of the basin drained through ditcches only. The percentage of nitrates (V) in the mineral nitrogen load was from 97% in drained water to 85% in water flowing through ditches and 83% in water discharged through drains and ditches.

5. The total nitrogen load carried away through the draining systems from agricultural basins was closely related to the amount of discharged water and water concentration of mineral nitrrogen compounds, especially N-NO_3. Due to the seasonal discharge of water, with the climax occurring in March-April, the largest loss of nitrogen from drained areas appears in spring.

6. Nitrates (V) made up the largest portion of total nitrogen polluting drained water, i.e. 92% of mineral N and 84% of total N in water flowing through drains, 88% of mineral N and 81% of total N in water drained trough ditches and drains and just 68% of mineral N and 59% of total N in water carried away through ditches.

7. The greatest threat of polluting surface water with nitrogen compound, due to the volume of its load discharged from sgricultural basins, occurred in spring, and the smallest one – in autumn and in summer.

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