J. Elementol. 2008, 13(4): 559-570

CHANGES IN MAGNESIUM CONCENTRATIONS AND LOAD IN RUNOFF WATER FROM NITRATE VULNERABLE ZONES*

Józef Koc, Małgorzata Rafałowska, Andrzej Skwierawski

Chair of Land Improvement and Environmental Management University of Warmia and Mazury in Olsztyn

Abstract

The objective of this study was to investigate magnesium concentrations and load, and to determine their seasonal changes in runoff water from catchments classified as nitrate vulnerable zones.

The results indicate that the average concentrations of 12.2 mg Mg$\cdot$dm^{-3}, with fluctuations within the range of 3.3 to 26.2 mg$\cdot$dm^{-3}, and average annual load of 14.3 kg Mg$\cdot$ha$^{-1}\cdot$year^{-1}, with fluctuations within the range of 4.8 to 41.6 kg Mg$\cdot$ha$^{-1}\cdot$year^{-1}, in runoff water from agricultural areas are determined by weather conditions (season), type of drainage system (ditches, drains) and fertilization intensity. In comparison with land drained by a network of drainage ditches, intensive farming in drained areas increases magnesium loss 2.5-fold from 10 kg per hectare of semi-intensively farmed area to 25 kg Mg$\cdot$ha^{-1} in an intensively farmed area. The highest magnesium loss was reported in the non-growing season, and around 46% of total magnesium load was leached out in the winter. The magnesium loss was minimized during harsh winters and summer draughts (to around 1.2 kg Mg$\cdot$ha$^{-1}\cdot$year^{-1}) due to a seasonal absence of runoffs.

Key words: magnesium, load, nitrate vulnerable zone, agricultural sources.

prof. dr hab. Józef Koc, Chair of Land Reclamation and Mangement, University of Warmia and Mazury, pl. Łódzki 2, 10-718 Olsztyn, Poland, e-mail: katemel@uwm.edu.pl
*The study carried out within Research Project No. N N305 1056 33 by the Ministry of Science and Higher Education.

DYNAMIKA STĘŻEŃ I ŁADUNKU MAGNEZU W WODACH ODPŁYWAJĄCYCH Z OBSZARÓW SZCZEGÓLNIE ZAGROŻONYCH SPŁYWAMI AZOTU ZE ŹRÓDEŁ ROLNICZYCH

Abstrakt

Celem pracy była analiza stężeń i ładunków magnezu oraz określenie ich sezonowych zmian w wodach odpływających ze zlewni zakwalifikowanych do obszarów szczególnie narażonych na zanieczyszczenia wód azotanami ze źródeł rolniczych.

Uzyskane wyniki świadczą o tym, że średnie stężenie 12,2 mg $Mg \cdot dm^{-3}$, z wahaniami od 3,3 do 26,1 $mg \cdot dm^{-3}$, i średni roczny ładunek 14,3 kg $Mg \cdot ha^{-1} \cdot rok^{-1}$, z wahaniami od 4,8 do 41,6 kg $Mg \cdot ha^{-1} \cdot rok^{-1}$, w wodach odpływających urządzeniami melioracyjnymi z obszarów rolniczych zależą od warunków meteorologicznych (pora roku), rodzaju systemu melioracyjnego (rowy, dreny) oraz intensywności nawożenia. Intensywne użytkowanie zdrenowanych gruntów ornych, w porównaniu z glebami odwadniającymi siecią rowów, powoduje ponad 2,5-krotny wzrost wymycia magnezu z 10 kg z 1 ha obszaru o średnio intensywnym rolnictwie do 25 kg $Mg \cdot ha^{-1}$ z obszaru intensywnego rolnictwa. Największy odpływ występował w okresie pozawegetacyjnym, ok. 46% ogólnej masy ładunku odpłynęło zimą. W okresie mroźnych zim oraz suszy letnich następuje minimalizacja odpływu magnezu (do ok. 1,2 kg $Mg \cdot ha^{-1} \cdot rok^{-1}$) w wyniku okresowego zaniku odpływu wód.

Słowa kluczowe: magnez, stężenie, ładunek, obszar szczególnie zagrożony, źródła rolnicze.

INTRODUCTION

In addition to the nutrient load carried by precipitation, surface water also contains substances drained from the soil and transported with surface runoffs from agricultural areas. The volume and intensity of nutrient migration is largely affected by the quantity of water runoff which, in turn, is determined by the geological structure of the catchment, relief features, soil class, soil's buffering and sorption capacity, type of catchment use and climatic conditions determining water flow and its availability for plants (SOLARSKI et al. 2000, KOC et al. 2002, LIPIŃSKI 2003). The quality of water varies seasonally due to changes taking place in the soil, biological sorption and changes in the soil's water balance in different seasons of the year (KOC et al. 1996, MILER et al. 2001). Mineral and organic fertilizer nutrients which are not plant available are partially leached out from the soil, transported to water-bearing horizons or directly to surface water. Intensive farming also leads to the evacuation of vital nutrients, including magnesium, a key element, essential for life processes (BOROWIEC et al. 1993, KOC 1999). Large quantities of magnesium are leached out from soils which are heavily fertilized with potassium and ammonium nitrogen as these elements have an antagonistic effect on exchange sorption. High level of mineral fertilization and regular application of high slurry rates containing K^+ and NH_4^+ could speed up magnesium loss.

The objective of this study was to investigate magnesium concentrations and load, and to determine their seasonal changes in runoff water from catchment areas classified as nitrate vulnerable zones.

MATERIALS AND METHODS

The study was carried out in 2005-2007 in the catchment of Lake Dobskie. The land in the lake's catchment is used by a farming estate, which covers a total area of 1,090 ha, including 841 ha of arable land. The farm specializes in hog production (around 2,600 head). The study covered four partial catchments of Lake Dobskie characterized by different fertilization intensity (intensive, semi-intensive and low intensity) and type of drainage system (ditches and drains – Figure 1):

Catchment no. 1 is an intensively farmed and drained catchment (521) of an area of 15.1 ha of arable land, soil quality class IIIb and IVa. In 2005 it was cropped with winter triticale. Mineral fertilization at a rate of N – 61 kg$\cdot$ha^{-1} and organic fertilization (animal slurry) at a rate of 20 m$^3\cdot$ha$^{-1}\cdot$year^{-1} were applied. In 2006, spring barley was grown on these fields, fed with the

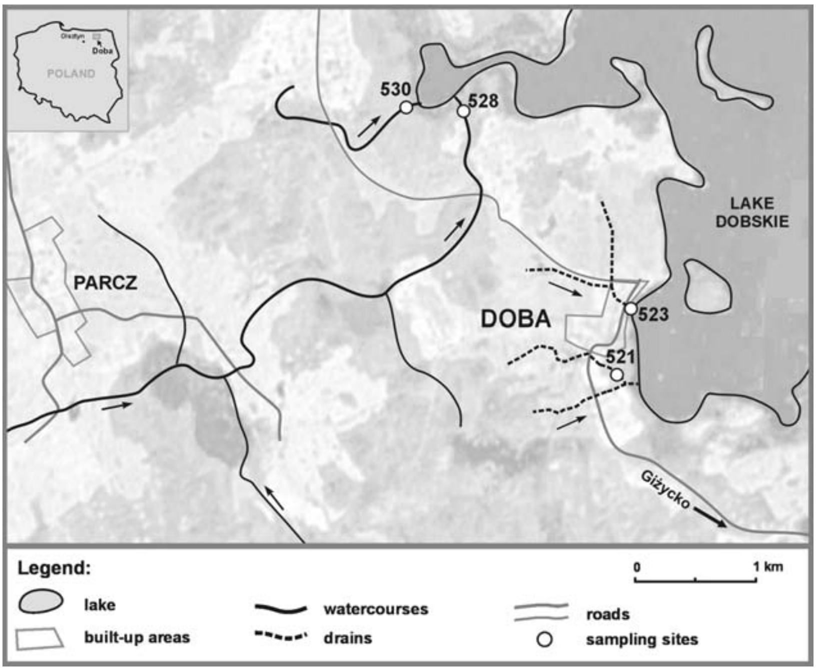

Fig. 1. Sampling sites in the catchment of Lake Dobskie

following fertilization rates: 98 kg N·ha^{-1}, 46 kg P_2O_5·ha^{-1}, 60 kg K_2O·ha^{-1}. Slurry was applied in June 2006. In 2007, winter rye was grown and fed 100 kg N·ha^{-1}, 52 kg P_2O_5·ha^{-1}, 50 kg K_2O·ha^{-1}.

Catchment no. 2 is a semi-intensively farmed and drained catchment (523) of an area of 41.7 ha. Situated in the vicinity of build-up areas in the village of Doba and a large farm, it consists of light soils of quality class V. The drainage system carries water away from fertilized farm fields (68 kg N·ha^{-1}, 40 kg P_2O_5·ha^{-1}, 55 kg K_2O·ha^{-1} in 2005 for oats, 88 kg N·ha^{-1}, 41 kg P_2O_5·ha^{-1}, 54 kg K_2O·ha^{-1} in 2006 for rye, and in 2007, the field was also sown with winter rye and the following fertilizer rates were applied: 140 kg N·ha^{-1}, 52 kg P_2O_5·ha^{-1}, 50 kg K_2O·ha^{-1}).

Catchment no. 3 is an intensively farmed catchment (528) covering the supply area of Pilwa Bay in the western part of Lake Dobskie. A surface watercourse drains an area of 1,616 ha which is 57%. afforested The watercourse was stagnant between July and October 2005 and between July and August 2006. Arable land in catchment no. 3 consists mostly of light loamy sands (soil quality class IV b). Triticale was grown in 2005, winter rape in 2006 and winter wheat in 2007. In the experimental period, the area was fertilized with 130 kg N·ha^{-1} and a spring – with slurry at the rate of 20 m^3·ha^{-1} in 2005, and 206 kg N·ha^{-1} in 2006. In 2007, winter wheat was fertilized with 130 kg N·ha^{-1}, 52 kg P_2O_5·ha^{-1}, 54 kg K_2O·ha^{-1}.

Catchment no. 4 is a semi-intensively farmed catchment (530) draining the western part of Pilwa Bay catchment. It covers an area of 109 ha and is 60% afforested. The remaining parts of the catchment are covered by arable land on loamy sands (soil quality class V). In the analyzed period, the watercourse was stagnant in the summer and autumn. In 2005, oat was fertilized with 100 kg N·ha^{-1}, 60 kg P_2O_5·ha^{-1} and 50 kg K_2O·ha^{-1}. In 2006 and 2007, rye was fertilized with 113 kg N·ha^{-1}, 44 K_2O·ha^{-1} and 136 kg N·ha^{-1}, 52 kg P_2O_5·ha^{-1}, 50 kg K_2O·ha^{-1}, respectively.

The investigated areas are made up of soils with an average magnesium content of 3.4 to 7.0 Mg·100 g soil.

In line with the recommendations of the Nitrates Directive (DIRECTIVE 1991), the analyzed catchments were classified as a nitrate vulnerable zone where nitrogen pollution from agricultural sources has to be limited. This was determined in view of the nitrate content of underground water reaching 95 mg·dm^{-3} (Directive 2004a).

The following physical and chemical properties of water in the investigated area were determined: pH by potentiometry, temperature with the use of a thermometer integrated with an oxygen probe, oxygen saturation with the use of a WTW Multiline P3 meter, and electrolytic conductivity with the use of a Hanna conductivity meter. The flow of drained water and watercourses falling into the lake was measured according to a sample collection with the use of a VALEPORT 801 electromagnetic flow meter. Water samples were collected once a month in 2005-2007 and magnesium concentrations were determined by colorimetry with the use of Titanium yellow. Laboratory analyses were performed in accordance with the generally observed standards (HERMANOWICZ et al. 1999). The values of precipitation volume and ambient air temperatures were supplied by the Institute of Meteorology and Water Management based on the readouts of the meteorological station in Kętrzyn. The results were verified statically with the use of the Statistica 7 application.

Seasonal variations in water runoff, magnesium concentrations and load were computed by classifying samples into groups according to the season in which they were collected: winter (January – March), spring (April – – June), summer (July – September) and autumn (October – December). Magnesium loss was determined by multiplying magnesium levels and water flow volume. Magnesium loss per ha was determined by dividing the obtained loss values by the area of the drained catchment.

RESULTS AND DISCUSSION

Significant variations in weather conditions affecting plant development, magnesium uptake, water runoff and the loss of waterborne nutrients were observed in the investigated period. Based on the total volume and distribution of precipitation, the analyzed years were divided into two categories (according to KACZOROWSKA 1962): normal year (2005 – 545 mm) and two wet years (2006 – 640 mm; 2007 – 646 mm) – Figure 2. Variations in ambient air temperature were also noted with the average of 7.7°C, 8.1°C and 8.8°C in the successive years of the experiment. Periodic drying-up of the watercourses was observed in the summer and in early autumn throughout the entire experimental period. Below-zero air temperatures noted between December 2005 and March 2006 and in February 2007 led to the formation of snow and ice cover on the ground surface. The thawing of precipitation water in April 2006 and March 2007 resulted in the leaching of micronutrients from the ground into the watercourse.

Magnesium concentrations in water are determined by the rate of magnesium discharge from the soil and biosorption. The above processes are affected by physical and chemical properties such as oxygen saturation of water, temperature, pH and conductivity (Table 1). The highest oxygen saturation was reported in the spring and summer due to the intensive growth of vegetation, which significantly alters the properties of water.

Significant variations were also noted in water electrolytic conductivity (550-815 $\mu S \cdot cm^{-1}$). Conductivity values indicate that the content of water-soluble substances is higher in water evacuated via drains than via open watercourses and ditches, particularly in the autumn (KOC et al. 2002).

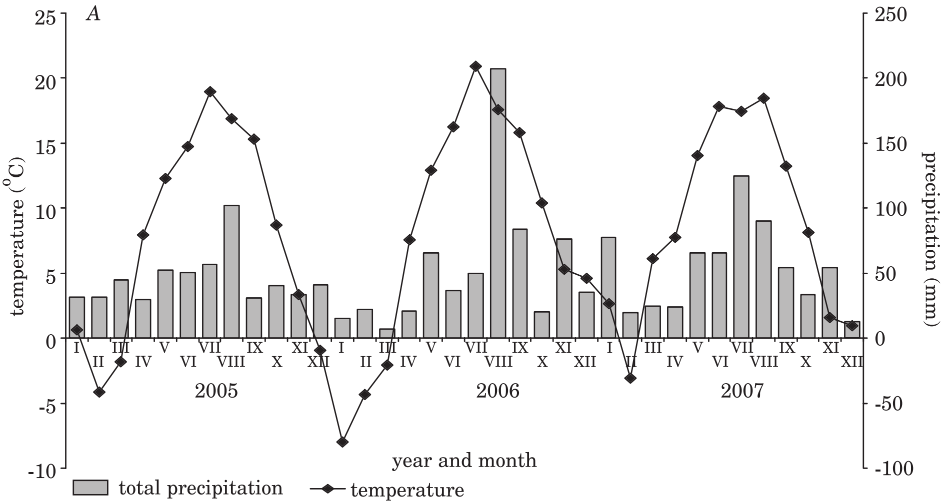

Fig. 2. Distribution of precipitation volume and ambient air temperature in 2005-2007

The fluctuations in Mg^{+2} levels in runoffs from agricultural catchments resulted from intensive farming as well as from the type of drainage system and weather conditions.

In the analyzed period, the above factors contributed to high variations in Mg^{+2} concentrations both in between and during the investigated years and seasons (Table 2).

An analysis of magnesium levels in water runoffs indicates that increased magnesium levels and the highest fluctuations in the range of 3.8 to 26.1 mg·dm^{-3} (SD=3.52, CV=49.45%) were noted in 2005, and fluctuations in the range of 3.3 to 15.7 mg·dm^{-3} (SD=3.52, CV=29.31%) were observed in 2007 in water drained from intensively farmed areas. Higher Mg^{+2} concentrations in runoffs from farming areas could be due to magnesium supplementation treatments as well as intensified Mg leaching from the soil in the non-growing season.

Lower fluctuations in magnesium levels (from 12.8 to 15.6 mg·dm^{-3} in 2006, and from 7.2 to 17.0 mg·dm^{-3} in 2007) were observed in watercourses with semi-intensively farmed catchments, and these findings are validated by the lowest standard deviation and coefficient of variation.

Throughout the entire experimental period, the highest magnesium levels, at 14.8 mg·dm^{-3} on average, were reported in the summer in water drained from intensively farmed areas (slurry application), although the analyzed nutrient was taken up by plants (Table 3). The above could be due to the fact that substances were dissolved in smaller quantities of water in seasons when more water was evaporated than precipitated (KOC et al. 2003). This hypothesis is supported by the electrolytic conductivity of water in the

Table 1

Seasonal variations in the physical and chemical properties of the inflows to Lake Dobskie in 2005-2007

Inflow (Type of use) \ Parameter	Season	Oxygen saturation (%)	Temperature (°C)	pH	Conductivity ($\mu S \cdot cm^{-1}$)
Drain 521 (intensive)	W*	58.3	4.5	7.2	762
	Sp	50.2	11.3	7.2	762
	Su	62.0	14.2	7.3	798
	A	62.0	7.5	7.3	815
	Y	58.1	9.1	7.3	782
Drain 523 (semi-intensive)	W	91.3	4.5	7.5	638
	Sp	84.4	9.6	7.6	672
	Su	92.4	13.6	7.6	681
	A	93.3	8.5	7.5	690
	Y	89.6	8.8	7.6	669
Watercourse 528 (intensive)	W	75.6	1.0	7.3	611
	Sp	73.0	17.0	7.8	612
	Su	86.0	15.4	7.7	550
	A	63.7	3.8	7.4	578
	Y	73.6	8.2	7.5	595
Watercourse 530 (semi-intensive)	W	89.2	1.3	7.7	580
	Sp	93.7	14.4	7.9	597
	Su	no flow			
	A	84.0	3.2	7.7	663
	Y	88.3	6.3	7.8	609

*W – winter; Sp – spring; Su-summer; A – autumn; Y – year

investigated period (Table 1). A slightly different trend was observed in water drained via watercourses. The highest Mg^{+2} concentrations of 14.1 $mg \cdot dm^{-3}$ were reported in the autumn in the watercourse draining semi- intensively farmed light soils, while the lowest levels at 11.3 $mg \cdot dm^{-3}$ were noted in runoffs from intensively farmed medium-heavy soils due to the biological sorption of magnesium by water vegetation. This process was not observed in water evacuated via drainage systems.

The highest seasonal fluctuations in magnesium levels (8.3-19.2 $mg \cdot dm^{-3}$) were observed in water evacuated by the drainage system from the most intensively farmed area (Table 3). The above was validated by the results of prior research conducted in the Olsztyn Lakeland (Koc, Szymczyk 2003).

Based on an analysis of correlations between the investigated parameters, a negative correlation was determined between temperature, conductivity and magnesium concentrations only in the drain evacuating water from a semi-intensively farmed area (Table 4).

Table 2

Magnesium concentrations in the inflows to Lake Dobskie in 2005-2007

Type of inflow Type of use	2005			2006			2007			Mean for 2005-2007		
	mean X ---------- range of values	standard deviation (SD)	coefficient of variation (%) CV	mean X ---------- range of values	standard deviation (SD)	coefficient of variation (%) CV	mean X ---------- range of values	standard deviation (SD)	coefficient of variation (%) CV	mean X ---------- range of values	standard deviation (SD)	coefficient of variation (%) CV
Drain (521) intensive	13.8 ---------- 3.8-26.1	6.83	49.45	12.2 ---------- 7.7-17.8	3.07	25.24	12.0 ---------- 3.3-15.7	3.52	29.31	12.7 ---------- 3.3-26.1	4.75	37.47
Drain (523) semi-intensive	12.9 ---------- 7.1-19.6	3.44	26.68	10.7 ---------- 5.5-13.6	2.48	23.19	11.8 ---------- 7.8-24.5	4.77	40.34	11.8 ---------- 5.5-24.5	3.69	31.30
Watercourse (528) intensive	11.0 ---------- 7.0-13.6	2.23	20.28	12.6 ---------- 7.0-17.6	3.01	23.82	12.6 ---------- 8.2-24.5	4.38	34.76	12.2 ---------- 7.0-24.5	3.44	28.23
Watercourse (530) semi--intensive	10.9 ---------- 8.0-14.6	2.29	21.03	13.8 ---------- 12.8-15.6	1.09	7.89	12.1 ---------- 7.2-17.0	3.02	24.95	12.1 ---------- 7.2-17.0	2.54	20.97

Table 3

Average seasonal magnesium concentrations (mg·dm^{-3}) in the inflows to Lake Dobskie in 2005-2007

Season	Type of inflow (type of use)	Year			Mean for 2005-2007
		2005	2006	2007	
Winter	drain 521 (intensive)	8.3	10.3	10.1	9.5
	drain 523 (semi-intensive)	9.3	10.8	15.5	11.9
	watercourse 528 (intensive)	10.0	12.0	15.6	12.5
	watercourse 530 (semi-intensive)	10.0	14.9	12.9	12.6
Mean		9.4	12.0	13.5	11.6
Spring	drain 521 (intensive)	17.2	13.7	11.8	14.3
	drain 523 (semi-intensive)	16.0	9.9	10.9	12.2
	watercourse 528 (intensive)	11.3	14.3	12.0	12.6
	watercourse 530 (semi-intensive)	10.5	12.8	8.8	10.7
Mean		13.8	12.7	10.9	12.4
Summer	drain 521 (intensive)	19.2	13.5	11.7	14.8
	drain 523 (semi-intensive)	13.9	11.0	9.0	11.3
	watercourse 528 (intensive)	dry	12.3	10.3	11.3
	watercourse 530 (semi-intensive)	dry	dry	dry	dry
Mean		16.5	12.3	10.3	12.5
Autumn	drain 521 (intensive)	10.6	10.6	14.5	11.9
	drain 523 (semi-intensive)	12.5	11.0	11.9	11.8
	watercourse 528 (intensive)	12.0	11.7	12.6	12.1
	watercourse 530 (semi-intensive)	14.6	13.4	14.3	14.1
Mean		12.4	11.6	13.3	12.5
Year	drain 521 (intensive)	13.8	12.2	12.0	12.7
	drain 523 (semi-intensive)	12.9	11.8	11.8	12.2
	watercourse 528 (intensive)	11.0	12.6	12.6	12.1
	watercourse 530 (semi-intensive)	10.9	13.8	12.1	12.3
Mean		12.1	12.6	12.1	12.3

The above supports the role of vegetation in removing Mg^{+2} from watercourses at favorable temperatures (KOC 1999).

A significant correlation (above 0.3) was observed between electrolytic conductivity and magnesium levels in water drained from an intensively farmed area. As confirmed by published sources, intensive fertilization supports the leaching of Mg^{+2} from the soil sorption complex (DOBRZAŃSKI, ZAWADZKI 1981).

The magnesium load evacuated by various means (ditches and drains) from farming areas was determined mostly by the level of farming intensity in the catchment (Table 5). Precipitation water collects and transports substances released from the soil into the water circulation system (PAŁKA-GUTOWSKA1996).

Table 4

Matrix of coefficients of correlation between magnesium concentrations and the selected physical and chemical properties of water in the inflows to Lake Dobskie

Inflow \ Parameter	Oxygen saturation (%)	Temperature (°C)	pH	Conductivity (µS·cm^{-1})
Drain 521 (intensive)	0.02	0.24	0.13	0.39*
Drain 523 (semi-intensive)	0.26	-0.09	-0.12	0.30
Watercourse 528 (semi-intensive)	0.12	-0.05	-0.13	-0.38
Watercourse 530 (low intensity)	-0.16	-0.57*	-0.38	0.57*

*correlations were marked as significant at $p< 0.05$

Table 5

Seasonal and annual variation (kg·ha^{-1}·year^{-1}) in magnesium outflows per area unit in the investigated catchments

Season	Type of inflow (type of use)	Year			Mean for 2005-2007
		2005	2006	2007	
Winter	drain 521 (intensive)	14.9	1.9	5.2	7.3
	drain 523 (semi-intensive)	8.4	1.2	6.9	5.5
	watercourse 528 (intensive)	6.9	0.60	12.0	6.5
	watercourse 530 (semi-intensive)	9.7	0.8	10.8	7.1
Mean		10.0	1.1	8.7	6.6
Spring	drain 521 (intensive)	16.1	6.5	6.2	9.6
	drain 523 (semi-intensive)	3.2	0.7	1.4	1.8
	watercourse 528 (intensive)	3.7	0.5	1.9	2.1
	watercourse 530 (semi-intensive)	2.1	0.2	0.7	1.0
Mean		6.3	2.0	2.5	3.6
Summer	drain 521 (intensive)	8.2	1.8	1.0	3.7
	drain 523 (semi-intensive)	1.3	0.3	1.0	0.9
	watercourse 528 (intensive)	dry	0.3	0.7	0.3
	watercourse 530 (semi-intensive)	dry	dry	dry	dry
Mean		2.4	0.6	0.7	1.2
Autumn	drain 521 (intensive)	2.4	9.9	1.9	4.7
	drain 523 (semi-intensive)	1.9	2.6	1.7	2.1
	watercourse 528 (intensive)	1.2	4.4	2.5	2.7
	watercourse 530 (semi-intensive)	0.6	4.0	1.9	2.2
Mean		1.5	5.2	2.0	2.9
Year	drain 521 (intensive)	41.6	20.0	14.2	25.3
	drain 523 (semi-intensive)	14.8	4.8	11.0	10.2
	watercourse 528 (intensive)	11.8	5.9	17.2	11.6
	watercourse 530 (semi-intensive)	12.4	5.0	13.4	10.3
Mean		20.2	8.9	13.9	14.3

The highest annual Mg^{+2} load (per area unit) of 41.6 kg $Mg \cdot ha^{-1} \cdot year^{-1}$ was evacuated in 2005 from an intensively farmed area, mostly in the winter (38%) and in the spring (39%), as the highest water runoffs and magnesium concentrations were reported in those seasons.

In the course of the three experimental years, an average of 14.3 kg Mg·year was discharged per ha of agricultural areas. As regards both analyzed drainage systems, the highest magnesium outflows were reported in an intensively farmed area where the resulting loss was 2.5 times higher than in watercourses draining intensively and semi-intensively farmed areas as well the semi-intensively farmed area connected to a drainage network. A similar dependency was noted by PULIKOWSKI et al. (2006). The highest Mg^{+2} loss was observed in the non-growing season, when around 46% of the relevant load (average for all catchments) was discharged in the winter due to magnesium leaching from the soil and the absence of magnesium uptake by plants (BANACH et al. 2007).

Water and magnesium runoffs may be inhibited during a harsh winter. The absence of flow reported every summer in the two investigated watercourses limited magnesium outflows and minimized the resulting loss to 1.2 kg $Mg \cdot ha^{-1} \cdot year^{-1}$ over the investigated period.

CONCLUSIONS

1. The magnesium load evacuated with water runoffs from agricultural areas is determined by weather conditions, which modify runoff volume, the intensity of farming operations in the catchment and the type of drainage system. The greatest magnesium losses are observed during mild winters in drained and intensively fertilized areas.

2. Farming intensity in the catchment affected magnesium concentrations in drainage outflows. The highest average magnesium level of 12.7 $mg \cdot dm^{-3}$ with fluctuations in the range of 3.3 to 26.1 $mg \cdot dm^{-3}$ were reported in water drained from an intensively farmed area. Variations in the magnesium content of drainage water resulting from the level of farming intensity did not exceed 30%.

3. Around 50% of magnesium loss from drained areas was reported during mild and wet winters. Magnesium outflows were not observed during harsh winters. Summer loss accounted for around 26% of the average annual magnesium load and it was inhibited during draughts.

4. Every year, an average of 14.3 kg of magnesium is drained to surface water from 1 ha of agricultural catchments. The magnesium loss from intensively farmed areas is 2.5 times higher than in catchments characterized by semi-intensive farming.

REFERENCES

BANACH B., SZCZUROWSKA A. 2007. *Chemical characterization of water from selected melioration ditches with different habitats (Poleski National Park).* Pol. J. Environ. Stud., 16 (2A): 56-61.

BOROWIEC S., PIEŃKOWSKI P. 1993. *Oddziaływanie geochemiczne i antropogeniczne na chemizm wód obszarów rolniczo-leśnych Pomorza Zachodniego. Geoekosystem obszarów rolniczych.* Ossolineum. (19-23).

DOBRZAŃSKI B. (red), ZAWADZKI S. (red). 1981. *Gleboznawstwo.* PWRiL, Warszawa, ss. 613.

DYREKTYWA 1991. *Dyrektywa Rady 91/676/EWG z dnia 12 grudnia 1991 r. w sprawie ochrony wód przed zanieczyszczeniem powodowanym przez azotany pochodzące ze źródeł rolniczych.*

HERMANOWICZ W., DOJLIDO J., DOŻAŃSKA W., KOZIOROWSKI B., ZERBE J. 1999: *Fizyczno-chemiczne badanie wody i ścieków.* Arkady, Warszawa, ss. 556.

KACZOROWSKA Z. 1962. Opady w Polsce w przekroju wieloletnim. Inst. Geog. PAN, Prz. Geogr., 33.

KOC J. 1999. *Badania nad przemieszczaniem magnezu do wód w środowisku rolniczym.* Cz. I. *Czynniki kształtujące zawartość magnezu w wodach powierzchniowych.* Biul. Nauk., 4 (1): 218-233.

KOC J., CYMES I., SZYMCZYK S. 2002. *Jakość wody w systemie melioracyjnym z wkomponowanymi małymi zbiornikami retencyjnymi.* Woda – Środowisko – Obszary Wiejskie, 2/1: 225-236.

KOC J., SZYMCZYK S. 2003. *Wpływ intensyfikacji rolnictwa na odpływ wapnia i magnezy z gleb.* J. Elementol. 8(4): 231-238.

LIPIŃSKI J., 2003. *Drenowanie gleb mineralnych a środowisko przyrodnicze.* Wiad. Mel. Łąk., 2: 74-76.

MILER A., LITERACKI D., PLEWIŃSKI D. 2001. *Jakość wód gruntowych w różnych siedliskach położonych wzdłuż transeptów odpływu.* Zesz. Nauk Post. Rol., 477: 93-100.

PULIKOWSKI K., KOSTRZEWA S., PALUCH J., SZEWRAŃSKI SZ. 2006. *Stężenie i ładunek magnezu oraz wapnia w odciekach drenarskich.* J. Elementol., 11(4): 483-493.

PYŁKA-GUTOWSKA E. 1996. *Ekologia z ochroną środowiska.* Wyd. Oświatowe, Warszawa, 279.

Rozporządzenie 2004a: Rozporządzenie Nr 5/2004 Dyrektora Regionalnego Zarządu Gospodarki Wodnej W Warszawie z dnia 20 kwietnia 2004 w sprawie wprowadzenia programu działań mających na celu ograniczenie odpływu azotu ze źródeł rolniczych dla obszaru szczególnie narażonego w gminach: Giżycko i Węgorzewo.

SOLARSKI H., KOC J., SOLARSKI K., ROCHWERGER A. 2000. *Stosunki wodne i hydrochemiczne w zlewni eksperymentalnej.* Zesz. Nauk. Kom. “Człowiek i środowisko”, 25: 2001-210.