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THE ROLE OF STORAGE RESERVOIRS IN REDUCING CALCIUM MIGRATION FROM AGRICULTURAL CATCHMENTS*

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Abstract

This study was conducted on a storage reservoir situated in a valley, in the lower course of the Sząbruk stream in north-eastern Poland, the Olsztyn Lakeland mesoregion. The catchment area of the Sząbruk stream consists of an agricultural and an afforested part. A storage reservoir is found in the lower part of the Sząbruk stream valley. The reservoir was built 25 years ago. It is enclosed by a dike and equipped with an outlet box. Outflows from the reservoir pass through the terminal segment of the Sząbruk stream to Lake Wulpińskie.

The results of the experiment indicate that the calcium content of water evacuated from the catchment was determined by the type and intensity of catchment use, ranging from 22.3 mg $Ca \cdot dm^{-3}$ to 178 mg $Ca \cdot dm^{-3}$. The highest calcium concentrations, 113 mg $Ca \cdot dm^{-3}$ on average, were noted in the agricultural catchment connected to a drainage network; lower levels, 78.7 mg $Ca \cdot dm^{-3}$, were found in farming areas drained via ditches, while the lowest Ca content in water, 38.7 mg $Ca \cdot dm^{-3}$ on average, was determined in outflows from afforested catchments. Calcium concentrations were lower during the growing season in all studied catchment types. The calcium load discharged from the catchment dependnded on the catchment management. The highest calcium loss per area unit was observed in the drained agricultural catchment (76.6 kg $Ca \cdot ha^{-1} \cdot year^{-1}$), followed by the catchment drained via ditches (56.3 $Ca \cdot ha^{-1} \cdot year^{-1}$) and the afforested catchment (31.8 $Ca \cdot ha^{-1} \cdot year^{-1}$). Despite the inflow of calcium-rich drainage water, calcium concentrations decreased by 11%, from 56.8 mg $Ca \cdot dm^{-3}$ to 50.3 mg $Ca \cdot dm^{-3}$, after the stream's waters passed through the storage reservoir. An increase in Ca levels was noted in the girdling ditch. The flow of water through the ditch minimizes sedimentation, and higher quantities of Ca were supplied with drainage water. The reservoir accumulated 242.4 kg Ca per ha in the course of one year, mostly in the growing season (83%). The above indicates high involvement of biological processes. The reservoir fulfilled the role of a barrier inhibiting calcium loss from the catchment.

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Key words: storage reservoir, agricultural catchment, calcium.

ZNACZENIE ZBIORNIKA RETENCYJNEGO W OGRANICZENIU MIGRACJI WAPNIA ZE ZLEWNI ROLNICZEJ

Abstrakt

Badania prowadzono na zbiorniku retencyjnym położonym w dolinie końcowego biegu strugi Sząbruk położonej w północno-wschodniej Polsce, w mezoregionie Pojezierza Olsztyńskiego. Zlewnia strugi Sząbruk składa się z części leśnej i rolniczej. W dolnej części doliny strugi Sząbruk jest położony zbiornik retencyjny wykonany przed 25 laty, zamknięty groblą i mnichem. Odpływy ze zbiornika kierowane są końcowym odcinkiem strugi Sząbruk do Jeziora Wulpińskiego.

W wyniku badań stwierdzono, że stężenie wapnia w wodzie odpływającej ze zlewni zależało od sposobu i intensyfikacji użytkowania i mieściło się w granicach od 22,3 mg $Ca \cdot dm^{-3}$ do 178 mg $Ca \cdot dm^{-3}$. Najwyższe stężenie, średnio 113 mg $Ca \cdot dm^{-3}$, wystąpiło w wodach zlewni rolniczych odwadnianych siecią drenarską, niższe, średnio 78,7 mg $Ca \cdot dm^{-3}$, w wodach z terenów rolniczych odwadnianych rowami, a najniższe, średnio 39,7 mg $Ca \cdot dm^{-3}$, w wodach ze zlewni leśnej. We wszystkich zlewniach cząstkowych mniejsze stężenia wapnia, stwierdzono w okresie wegetacyjnym niż poza nim. Ładunek wapnia odprowadzany z obszaru zlewni był uzależniony od sposobu jej zagospodarowania. Największy odpływ wapnia z jednostki powierzchni stwierdzono w zlewni rolniczej zdrenowanej (76,6 kg $Ca \cdot ha^{-1} \cdot rok^{-1}$), mniejszy ze zlewni odwadnianej rowami (56,3 kg $Ca \cdot ha^{-1} \cdot rok^{-1}$) i najmniejszy ze zlewni leśnej (31,8 kg $Ca \cdot ha^{-1} \cdot rok^{-1}$). W wyniku przepływu wody przez zbiornik retencyjny następowało zmniejszenie w niej stężenia wapnia o 11%, z 56,8 mg $Ca \cdot dm^{-3}$ do 50,3 mg $Ca \cdot dm^{-3}$, pomimo zasilania zasobnymi w wapń wodami drenarskimi. W wodach przepływających rowem opaskowym stwierdzono wzrost stężeń Ca, gdyż w czasie przepływu rowem procesy sedymentacji są dużo mniejsze, a o wzroście stężeń zadecydowało zasilanie wodami drenarskimi. W ciągu roku w misie zbiornika zostało zakumulowane 242,4 kg Ca na 1 ha jego powierzchni, z czego większość (83%) w okresie wegetacyjnym. Świadczy to o istotnym udziale procesów biologicznych. Zbiornik retencyjny pełnił funkcję bariery zatrzymującej odpływ związków wapnia ze zlewni.

Słowa kluczowe: zbiornik retencyjny, zlewnia rolnicza, wapń.

INTRODUCTION

Calcium ions are the predominant ions in water migrating from agricultural catchment areas. For farming needs, the calcium content of soil has to be regularly supplemented through the use of calcium fertilizers. Surface waters contain high levels of calcium due to the leaching of this element from soil, which is a natural and unavoidable process. It results from the open circulation of substances in agricultural ecosystems and their environmental dispersion at every level of the trophic and geochemical cycles. In addition to intensive farming practices, calcium leaching is also supported by acid precipitation, which leads to soil acidification (BOWSZYS et al. 2005). The problem of calcium concentrations in water should be viewed from a different perspective than typical contamination or eutrophication. Calcium significantly affects the physical and chemical properties of water, including its pH (environmental alkalinization), carbonate (carbonate precipitation), sulfate and phosphate concentrations, as well as the coagulation of colloids. As a nutrient, calcium also has a profound effect on hydrobiological processes. Calcium content in water from agricultural catchment areas has been investigated by few researchers, although calcium concentrations contribute to biological, physical and chemical processes that determine the characteristic properties of water and bottom sediments in water bodies. Calcium levels in water are determined mainly by the volume of calcium load evacuated from the catchment area as well as fixation and sedimentation processes. Calcium is precipitated at the bottom of water bodies in the form of carbonates and organic residues as calciferous gyttia deposits (FÖLLMI 1989, KRAJEWSKI 1984). By fixing other elements, including heavy metal colloids, precipitated calcium compounds retain various pollutants.

The objective of this study was to investigate the role of storage reservoirs as barriers reducing the pollution of water evacuated from agricultural catchments, their effect on the migration of calcium compounds from agricultural catchments to surface waters, and their contribution to changes in calcium concentrations and accumulation in the environment.

MATERIALS AND METHODS

The role of a storage reservoir in calcium migration from an agricultural catchment area was analyzed during the hydrological years 2005/2006 and 2006/2007. The investigated storage reservoir is situated in a valley, in the lower course of the Sząbruk stream in north-eastern Poland, in the Masurian Lakeland macroregion and in the Olsztyn Lakeland mesoregion, 10 km south-west of Olsztyn. The catchment area of the Sząbruk stream consists of an agricultural and an afforested part. The afforested part of an area of 4.4 km^2 occupies 33% of the total catchment area of 13.2 km^2 (Figure 1). The storage reservoir of an area of 24.8 ha and a maximum depth of 1.5 m is found in the lower part of the Sząbruk stream valley. It is enclosed by a dike and equipped with an outlet box. The reservoir was built in the 1980s as a fish farming pond, but currently is not used for production purposes. In the western part, the reservoir is enclosed by a girdling ditch which regulates water flow by evacuating excess water to the Sząbruk stream. Outflows from the reservoir pass through the terminal segment of the Sząbruk stream to Lake Wulpińskie. The experiment covered the Sząbruk stream and the inflows and outflows of the storage reservoir (Figure 1).

Water flow rates in the Sząbruk stream were measured below the afforested catchment, at the reservoir inflow (outflow from the agricultural catch-

Fig. 1. Map of Sząbruk stream catchment area: 1 – Sząbruk stream below the afforested catchment, 2 – Sząbruk stream above the storage reservoir, 3 – inflow from the drained catchment to the storage reservoir, 4 – inflow from the drained catchment to the girdling ditch, 5 – outflow from the storage reservoir, 6 – outflow from the girdling ditch, 7 – inflow to Lake Wulpińskie

ment, inflow to the storage reservoir and to the girdling ditch), at the drainage outflow to the girdling ditch, at the drainage outflow to the storage reservoir, at the outflow from the reservoir, at the outflow from the girdling ditch and at the inflow to Lake Wulpińskie. Flow measurements were performed weekly with the use of a VALEPORT electromagnetic flow meter. The volumetric method was applied at low flow levels (below 2 $dm^3 \cdot s^{-1}$). Water samples for physical and chemical analyses were collected every two months at the flow measurement points, and Ca^{2+} levels were determined by atomic absorption spectrophotometry in line with the generally observed standards (HERMANOWICZ et al. 1999).

The calcium load evacuated from the catchment, supplied to and discharged from the reservoir, was calculated by summing up the product of average monthly flows and the corresponding calcium concentrations.

RESULTS AND DISCUSSION

The results of the study showed significant variations in calcium concentrations in different segments of the Sząbruk stream, in the inflows and outflows from the storage reservoir and the girdling ditch, and in the inflows to Lake Wulpińskie, subject to the type of catchment area (Table 1). The lowest calcium levels were noted in the Sząbruk stream below the afforested catchment, which is attributable to the continued leaching of calcium from the afforested catchment and insufficient calcium supplementation from precipitation and weathering. Higher calcium levels were determined in stream inflows from the agricultural catchment, at 78.7 mg $Ca \cdot dm^{-3}$ on average. The above increased the average Ca content of stream outflows from the combined afforested and agricultural catchments to 56.8 mg $Ca \cdot dm^{-3}$. High calcium concentrations, at 113 mg $Ca \cdot dm^{-3}$ on average, were noted in outflows from drained catchments. Higher calcium content of outflows from arable land could be attributed to the use of mineral and organic fertilizers (SAPEK 1996). Fertilizer components participate in exchange processes in the soil, and excess nutrients not absorbed by plants are transferred deeper into the soil and ground waters. The movement of calcium from the soil solution to ground and drainage waters is the main cause of soil depletion. Adequate calcium levels have to be maintained to ensure the soil's optimal properties. Calcium concentrations decreased as a result of water flow through the storage reservoir – by 11% on the annual basis and by 24% in the growing period. The observed calcium content of outflows from the storage reservoir was similar to calcium concentrations in outflows from small, mid-field ponds (54.7 mg $Ca \cdot dm^{-3}$ and 55.4 mg $Ca \cdot dm^{-3}$ on average respectively) on brown and black soils of the Masurian Lakeland (CYMES, SZYMCZYK 2005), and to calcium levels in the outflows from Lake Ardung (60.5 mg $Ca \cdot dm^{-3}$) noted

Table 1

Average calcium concentrations at the investigated sites (n=12)

Specification	Ca ($mg \cdot dm^{-3}$)					
	hydrological years 2005/2006 and 2006/2007		non-growing period		growing period	
	average	range	average	range	average	range
Sząbruk stream below the afforested catchment	39.7	22.3-49.2	36.5	22.3-49.2	42.8	22.3-49.2
Sząbruk stream above the storage reservoir	56.8	43.4-72.4	56.1	43.4-72.4	57.5	43.4-72.4
Inflows from the drained catchment to the storage reservoir	112.3	81.0-166.0	120.8	81.0-166.0	102.2	81.0-166.0
Inflow from the drained catchment to the girdling ditch	114.5	86.8-178.0	112.1	86.8-178.0	117.0	86.8-178.0
Outflows from the storage reservoir	50.3	34.8-67.5	57.0	34.8-67.5	43.6	34.8-67.5
Outflows from the girdling ditch	88.6	65.2-130.0	90.9	65.2-130.0	86.3	65.2-130.0
Inflows to Lake Wulpińskie	75.0	62.8-126.0	77.3	62.8-126.0	72.3	62.8-126.0

in a study carried out in the Olsztyn Lakeland (Koc et al. 2006). A comparison of Ca concentrations in the Sząbruk stream after passage through the storage reservoir and the girdling ditch showed a greater decrease in the calcium content of reservoir water than of stream water. Once the outflows from the storage reservoir and the girdling ditch were mixed, the average calcium load supplied to Lake Wulpińskie reached 75.0 mg $Ca \cdot dm^{-3}$.

An annual calcium balance was developed for different parts of the Sząbruk stream's catchment area (Table 2). The results of the study indicate that along a section stretching from the stream's source to a point situated above the storage reservoir, Sząbruk's waters carried 34.8 t $Ca \cdot year^{-1}$. The outflows from the afforested catchment carried 13.7 t $Ca \cdot year^{-1}$. The above findings supported the conclusion that the Sząbruk stream collected 21.1 t $Ca \cdot year^{-1}$ during its passage through the agricultural catchment. Annual calcium outflows per hectare of the catchment area increased after the stream's waters passed from woodland areas to agricultural areas. The calcium loss from afforested areas reached 31.8 kg $Ca \cdot year^{-1}$, and it was higher than the amount of calcium evacuated from the catchment above the storage reservoir (36.4 kg $Ca \cdot ha^{-1} \cdot year^{-1}$). The average Ca outflow from arable land drained via a ditch network was 49.2 kg $Ca \cdot ha^{-1} \cdot year^{-1}$. The calcium loss from drained catchments reached 76.0 kg $Ca \cdot ha^{-1} \cdot year^{-1}$.

Table 2

Calcium load at various points of the catchment

Specification	Total Ca load ($kg \cdot year^{-1}$)			Ca load ($kg \cdot ha^{-1} \cdot year^{-1}$)
	hydrological years 2005/2006 and 2006/2007	non-growing period	growing period	hydrological years 2005/2006 and 2006/2007
Sząbruk stream below the afforested catchment	13 657	5022	8634	31.8
Sząbruk stream above the storage reservoir	34 762	137 230	21 032	36.4
Inflows from the Sząbruk stream to the storage reservoir	23 418	9183	14 236	-
Inflows from the Sząbruk stream to the girdling ditch	11 433	4637	6796	-
Inflows from the drained catchment to the reservoir (agricultural catchment)	2719	1163	1556	75.5
Inflows from the drained catchment to the girdling ditch (agricultural catchment)	5483	1523	3960	76.6
Outflows from the storage reservoir	20 124	9330	10 794	-
Outflows from the girdling ditch	19 470	9027	10 444	-
Inflows to Lake Wulpińskie	39 595	18 357	21 238	38.8

The Sząbruk stream was divided above the storage reservoir, as a result of which part of its waters were fed directly to the reservoir, while the remaining flow was evacuated via the girdling ditch. According to the annual balance, the storage reservoir accumulated 31.8 kg $Ca \cdot ha^{-1} \cdot year^{-1}$ (Table 3). A decrease in the calcium load could be attributed to the formation of insoluble or sparingly soluble calcium compounds as well as to sedimentation (carbonates, sulfates and phosphates) (FÖLLMI 1989, KRAJEWSKI 1984). Calcium was accumulated mainly in the growing period (83% of annual accumulation) when the calcium load in water flowing through the storage reservoir was clearly lower. The reservoir accumulated 1.014 kg $Ca \cdot ha^{-1} \cdot year^{-1}$. The above suggests that calcium binds with the phosphate form released during the decomposition of fresh organic matter and deposits in the warm season of the year, and that it forms insoluble calcium carbonate that binds with hydrated excess carbon dioxide. Calcium could also be

Table 3

Calcium balance in the inflows from the Sząbruk stream catchment to the lake

Specification		Ca load ($kg \cdot year^{-1}$)			
		stream and girdling ditch	drainage network	inflow to Lake Wulpińskie	difference (Ca reduction in the reservoir)
Hydrological year	excluding the reservoir	42 889	2719	45 608	6012
	including the reservoir	42 889	2719	39 596	
Non-growing season	excluding the reservoir	18 210	1163	19 373	1014
	including the reservoir	18 210	1163	18 359	
Growing season	excluding the reservoir	24 679	1556	26 235	4998

absorbed by the reservoir's vegetation in amounts reaching 16.6 kg $Ca \cdot ha^{-1} \cdot year^{-1}$ (KOC, SZYPEREK 2003). On average, the reservoir accumulated 242.9 kg Ca per ha, including 201.5 kg (83%) in the growing season and only 40.9 kg (17%) in the winter. A much higher drop in calcium concentrations and loads in the reservoir over the growing period is indicative of intense biological processes during which the investigated element is fixed and accumulated in bottom deposits. The accumulation of calcium compounds in bottom deposits was also noted during a previous study of the storage reservoir in Sząbruk (KOC, SKONIECZEK 2006). The authors found that the calcium content of a dry deposit sample collected in the terminal segment of the reservoir was 2.5% at a depth of up to 10 cm and 9.3% at a depth of 10 to 20 cm. Different results were reported in respect of calcium concentrations and loads in the girdling ditch parallel to the analyzed reservoir. Ditch water was additionally supplied with calcium by inflows from the drainage network (5.3 t $Ca \cdot year^{-1}$) and by percolation. For this reason, calcium accumulation levels were measured in both the reservoir and the girdling ditch. A total of 45.6 t $Ca \cdot year^{-1}$ was discharged to the catchment, of which 39.6 t $Ca \cdot year^{-1}$ was evacuated from the girdling ditch and the storage reservoir to Lake Wulpińskie. The average calcium load discharged from the entire catchment area to the lake decreased by 13%, from 44.7 kg $Ca \cdot ha^{-1} \cdot year^{-1}$ to 38.8 kg $Ca \cdot ha^{-1} \cdot year^{-1}$.

CONCLUSIONS

1. The calcium content of water evacuated from the catchment was determined by the type and intensity of catchment use. The highest calcium outflows per area unit were noted in the agricultural catchment connected to a drainage network, lower concentrations were found in the catchment drained via ditches, while the lowest Ca content of water was determined in the outflows from afforested catchments. Calcium concentrations were lower during the growing season in all studied catchment types.

2. Calcium concentrations decreased by 11%, from 56.8 mg $Ca \cdot dm^{-3}$ to 50.3 mg $Ca \cdot dm^{-3}$, following the passage of the stream's waters through the storage reservoir. An increase in Ca levels was noted in the water flowing through the girdling ditch.

3. The reservoir accumulated 242.4 kg Ca per ha in the course of one year, mostly in the growing season (83%). The above indicates high involvement of biological processes. The reservoir fulfilled the role of a barrier inhibiting calcium loss from the catchment.

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