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Impact of Biogeochemical Barriers on the Migration of Chemical Compounds with the Water of Agricultural Landscape

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Abstract

The contents of calcium, magnesium and mineral carbon were investigated in the ground and surface water of shelterbelts and also in four small ponds of different surroundings as well as in water-courses of agricultural landscape. In these studies, differences among the concentrations of calcium, magnesium and mineral carbon were attributed solely to different surroundings of the ponds and water-courses, and also to width of the shelterbelt. The biogeochemical barrier in the form of shelterbelt efficiently decreases the concentration of chemical substances included in the dry mass from 30 to 75%, calcium from 20 to 54%, magnesium from 46 to 72% and also mineral carbon from 58 to 71%. The smallest contents of every investigated substance characterized the water of pond surrounded by a wide zone of meadow.

Keywords: shelterbelt, biogeochemical barrier, calcium, magnesium and mineral carbon in surface and ground water

Introduction

Long-term investigations carried out in the Wielkopolska region (Western Poland) by the Research Centre for Agricultural and Forest Environment of the Polish Academy of Sciences in Poznań, revealed high contents of chemical compounds including calcium and magnesium ions leaching with ground water from adjoining cultivated fields [18, 19, 21]. Due to the high mobility of these ions in soil profile, they simultaneously wash away from soil into ground water. Both ions apparently migrate in the form of mineral salts and also mineral-organic complexes [1, 22]. The decrease of their concentrations in sorptive complex due to excessive leaching is a negative effect. They are available and indispensable nutrients for plants and also definitely and significantly participate in biological, physical, chemical and biochemical processes in soils [11].

Our earlier investigations have shown that biogeochemical barriers in the form of meadows and shelterbelts separating cultivated fields from water-courses as well as small ponds are significantly impacted by the spread of chemical pollution in agricultural landscape [6-10].

This paper is the continuation of these researches and deals with the problem of estimation of the concentrations of calcium and magnesium and also mineral carbon in the surface and ground water of agricultural landscape. These investigations should clarify the arrangement of the degree of the limit the migration of mineral compounds with ground water through biogeochemical barrier. The study reported herein was conducted to achieve the optimum width of shelterbelt for the function as biogeochemical barrier. At present, insufficient data are

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available on the interaction of shelterbelts as biogeochemical barriers for the spread of these compounds in agricultural landscape. Additionally, the results obtained from all the experiments should give a better insight into the changes, which take place in the landscape affluent with functional elements as biogeochemical barriers.

Material and Methods

The investigations were carried out in Chlapowski's Agroecological Park situated 40 km southwest of Poznań. This area is located on loamy soils, which contain 70% cultivated fields, 12% meadows and pastures and approximately 14% afforestations including a well-developed network of shelterbelts.

Four small ponds of different surroundings and small water-courses of different agricultural areas were chosen for our research. Ground water under cultivated fields, meadow and shelterbelts and also surface water of small ponds and water-courses from the artificial wells once a month for 5 years from 1995 to 1999 was sampled and investigated. Ground water under shelterbelt flows away from adjoining cultivated field and passing through the shelterbelt. The first distance of this shelterbelt 104 m long is located on mineral soils next from 104 to 125 m on mineral organic soils. A detailed description of experimental setup has been given by Szajdak and Życzyńska-Bałoniak [16]. Principal results concerning the properties of soil organic matter and of chemical soil properties have been reported recently [15].

The direction of water flow was estimated on the basis of the level of the water in the wells. The shelterbelt includes different species dominated by maple, ash, beech, and hawthorn. Water samples were taken along the transect 125 m long passing through the afforestation in order to characterize chemical compounds (Table 1). The concentrations of Ca^{+2} and Mg^{+2} and also mineral carbon, as soon as pH were studied by examining ground water filtered by the filter paper Whatman GT/C. The concentrations of calcium and magnesium were investigated by the method of Hermanowicz [2]. Dry masses were isolated by the freeze-dried and drying to the constant of weight at 105°C.

Total amount of yearly rainfall was in 1995 – 705 mn, 1996 – 788 mn, 1997 – 765 mn, 1998 – 824 mn, and 1999 – 677 mn. Mean temperatures ranged from 8.52 to 10.14°C. The highest temperature +30°C was measured in July 1995, and the lowest -16°C observed in February 1996. The precision based on replicate analyses, were ± 0.01 for pH measurements, ± 4% for Ca^{+2}, ± 3% for Mg^{+2}, ± 4% for dry mass. All the determinations were run in triplicate, and the results were averaged.

Results and Discussion

The investigations of dry masses according to different places are given in Table 1. They revealed high variability of chemical compounds in ground waters. Yearly mean content of dry mass in ground water of the different agricultural areas ranged from 769.9 mg/l to 1179.6 mg/l (Table 1). The highest content was determined in April after thawing snow and also in September and October. The quantity of dry mass in ground water under cultivated field was equal to 1351.6 mg/l.

Yearly mean contents of calcium in ground water under cultivated field ranged from 234.9 mg/l to 373.8 mg/l. But yearly mean concentrations of magnesium were significantly smaller than calcium and ranged from 20.8 mg/l to 29.8 mg/l. However, yearly mean contents of inorganic carbon ranged widely from 62.2 mg/l to 184.5 mg/l and were seen to be between those for the concentrations of calcium and magnesium (Table 1). The concentrations of all determined compounds generally increased in 1995. Nevertheless, in most cases these concentrations of all investigated substances systematically and permanently decreased during the next years.

Distribution of calcium and magnesium and also inorganic carbon in the surface water of four small ponds of different surroundings is shown in Table 1. The first one was artificial and the second was natural surrounded by cultivated fields. A wide zone of meadow was surrounded by a third one. A fourth, was located in the hollow surrounded by the zone of meadow, cultivated field and 140-year old shelterbelt, included mainly *Robinia pseudacacia*. Due to water runoff the pond surrounding the cultivated field and located in the hollow was the most polluted. The distribution of dry mass in these two ponds during 5 years ranged from 455.0 to 689.2 mg/l. Mean contents of calcium, magnesium and inorganic carbon ranged from116.0-176.7 mg/l, 13.5-21.7 mg/l, and 32.7 to 48.9 mg/l, respectively. However, the smallest contents of every determined substance characterized the water of pond surrounded by wide zone of meadow (Table 2).

High contents of mineral compounds were determined in wide water-courses. Four yearly mean content of dry mass ranged from 719.2 to 1354.7 mg/l. Moreover, the concentrations of calcium ranged from 187.9 to 396.3 mg/l, magnesium from 20.1 to 28.4 mg/l and inorganic carbon from 45.4 to 75.8 mg/l (Table 3).

Table 1. Yearly mean contents from 1997 to 1999 of mineral compounds in ground water under cultivated fields in mg/l.

Ground water under cultivated fields	Dry mass	Ca^{+2}	Mg^{+2}	C_{min}
1	769.9	234.9	20.8	62.2
2	1100.6	363.6	28.9	157.7
3	1179.6	373.8	29.8	184.5

C_{min} – mineral carbon, 1-3 – places of sampling of ground water in different cultivated fields of this area.

The changes of mineral substances in ground water passing through the wide old leafy shelterbelt also were investigated. As reported by Szajdak and Życzyńska-Bałoniak [16] and Szajdak et al. [24] and in presented studies, the concentrations of chemical compounds determined in dry mass of ground water flowing away from cultivated fields to the shelterbelt were high and in 1995 where equal to 4996.0 mg/l. However, 5 yearly mean content was 1839.0 mg/l (Table 4). Like the contents of dry masses, the concentrations of calcium and magnesium systematically decreased during the entire period of the investigations. Yearly mean content of calcium in 1995 was equal to 349.7 mg/l and in 1999 decreased to 175.0 mg/l. The highest mean content of magnesium was determined in 1995 and equaled 77.3 mg/l, and in next years decreased to 35.6 mg/l (Table 5). During 5 years of investigations the yearly mean contents for calcium as well as magnesium decreased and equaled 49.9% and 53.8%, respectively. Long-term investigations on leaching carried out in the Research Centre for Agricultural and Forest Environment of the Polish Academy of Science showed, that due to process the concentration of calcium and magnesium and also many organic compounds released from soils and increased in ground water [3, 4, 5, 23]. The reason for high quantities of calcium and magnesium in ground water passing through the shelterbelt from the cultivated field was liming in these years. The high rainfall in June 1995 (105.3 mn) activated the migration of these ions, which influenced their high concentrations of dry mass [24].

Dissolved organic matter leached from soil could carry with it nutrient cations such as Ca^{2+} and Mg^{2+}. This makes the study of dissolved organic matter even more important. Many of the functional groups of dissolved organic matter are acidic and deprotonated, resulting in anionic charged matter which facilitates its solubility and ability to complex with metals. The reverse was found for the concentrations of mineral carbon than calcium and magnesium. This phenomenon may result in high mineralization of organic matter in ground water under the shelterbelt. The smallest yearly mean content of inorganic carbon was observed in 1995 and 1996, 108.0 and 107.5 mg/l, respectively. In following years we found increasing of mineral cation the concentrations, averaged 23% (Table 5).

Researches have shown the strong impact of rainfall on the changes of the concentrations of dissolved chemical compounds in ground water passing through the shelterbelts [12]. The dynamic migration of those compounds achieved from cultivated fields to shelterbelts were re-

Table 2. Yearly mean contents of mineral compounds in water of small ponds in mg/l.

Ponds	Dry mass	Ca^{+2}	Mg^{+2}	C_{min}
New pond	478.5	121.5	21.1	33.5
Pond surrounded wide zone of meadow	689.2	176.7	21.7	42.4
Pond surrounded cultivated fields	630.1	131.5	19.1	48.9
Pond surrounded wide zone of meadow	455.0	116.0	13.5	32.7

C_{min} – mineral carbon.

Table 3. Yearly mean contents from 1993 to 1996 of mineral compounds in water-courses in mg/l.

Place of sampling	Dry mass	Ca^{+2}	Mg^{+2}	C_{min}
Ditch Wyskoć surrounded by wide zone of meadow	719.2	187.9	28.4	45.4
Small mid-field channels				
1	1354.7	396.3	25.5	46.0
2	966.8	291.3	27.3	75.8
3	802.8	225.2	20.1	62.9

1-3 – small mid-field channels located in the different cultivated fields, C_{min} – mineral carbon.

Table 4. Yearly mean contents of concentrations of dry mass in ground water under shelterbelts in mg/l.

Ground water under shelterbelts	Years of investigations					Yearly mean content from 1995 to 1999
	1995	1996	1997	1998	1999	
Mineral soils						
Supply from the field	2544.4	1828.7	1925.7	1645.8	1251.0	1839.0
After flow of 16.5 m	647.2	860.5	698.0	537.7	872.2	723.1
After flow of 45.5 m	537.9	543.2	547.3	503.2	521.3	530.6
Mineral-organic soils						
After flow of 104 m	871.1	803.2	919.0	940.6	1236.0	954.0
After flow of 125 m	-	-	697.6	861.6	1118.8	892.7

flected from 5 to 8 months. Strong rainfall in August 1996 (203.7 mn) appeared to play an important role in the highest concentrations of chemical compounds in ground water under shelterbelt in January 1997. However, intensive rainfall in July and August 1997 impacted on the highest content of chemical compounds in ground water flows to shelterbelts after 8 months, in April 1998 (Fig. 1). Clearly the highest concentrations of chemical compounds respond to periods of rainfall. A significant correlation between the rainfall and the concentration of chemical compounds in ground water was observed. In our earlier studies the impact of rainfall on the contents of nitrogen substances in ground water also was found [12, 17].

Concentrations of all investigated chemical compounds in ground water passing through 16.5 m of the shelterbelt significantly decreased. The highest decrease of dry mass was observed in 1995. In this year the concentrations of dry mass in ground water passing through 16.5 m wide of shelterbelt decreased 75%. Moreover, the concentrations of calcium in this period decreased from 20 to 54% and magnesium from 46 to 72% as well as mineral carbon from 58 to 71% (Tables 4, 5).

Our earlier investigations [14, 15, 24] showed the highest significant decrease of organic carbon and humic substances after flow of ground water through the 16.5 m-wide shelterbelt. The concentrations of organic carbon decreased from 55 to 63% and humic substances from 69 to 79.5%. One of the reasons for different decrease of mineral substance passing through every distances of shelterbelt depends on different properties of mineral and mineral-organic soils. Mineral soils are

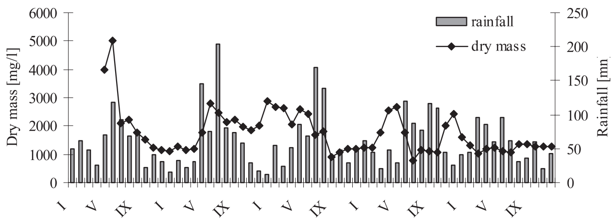

Fig. 1. Changes of chemical compounds (dry mass) in ground water flowing from cultivated fields to the shelterbelt [mg/l].

Table 5. Mean contents of the concentrations of Ca^{+2} and Mg^{+2} in ground water under shelterbelts in mg/l.

Ground water					
Year of investigations	Flow to the shelterbelt	After the following distances of the shelterbelt			
		Mineral soils		Mineral-organic soils	
		16.5 m	45.5 m	104 m	125 m
Ca^{+2}					
1995	349.7	162.5	131.5	234.0	-
1996	241.8	194.6	136.5	213.5	-
1997	278.9	176.5	147.7	254.9	201.6
1998	239.7	143.7	129.0	250.5	256.3
1999	175.0	129.0	142.0	340.0	327.2
Mg^{+2}					
1995	77.3	21.6	20.2	340.0	-
1996	49.8	27.0	22.7	256.7	-
1997	61.3	23.9	20.5	28.5	22.5
1998	47.9	18.4	19.6	22.6	37.3
1999	35.6	37.9	22.1	43.2	49.0
C_{min}					
1995	108.0	35.5	30.2	42.1	-
1996	107.5	39.6	33.2	41.3	-
1997	38.3	38.3	31.6	48.6	44.7
1998	121.9	35.6	28.6	47.7	52.2
1999	112.7	47.0	31.5	58.9	54.2

C_{min} – mineral carbon.

acidic (pH 3.9-5.2), and mineral-organic belong to neutral (pH 6.9-7.4) [17]. Higher acidity of mineral than mineral-organic soils may impact on the high removal of calcium and magnesium from their inorganic compounds and mineral-organic complexes of these soils. Szajdak et al. [17] have proved significant differences of humic compounds investigating various analytical techniques and isolated from these two different soils under shelterbelt. The highest maturity and thermal stable humic acids were characterized in the edge of shelterbelt and adjoining cultivated field. The activity of urease, the concentrations of total nitrogen, nitrates and ammonium were also the highest in the edge of shelterbelt. Respecting the nature of humic acids these substances characterize the high potential of complexity of metal including calcium and magnesium. Our results concerning the first distance of shelterbelt located on mineral soils suggest that the highest decrease of these ions may depend on complexity and maturity and also stability of humic substances. These dates are supported by findings of Szajdak et al. [14, 15], Szajdak and Maysner [13], Szajdak and Życzyńska-Bałoniak [16].

Our earlier research on the influence of meadow on the process of purification of ground water have shown that a significant decrease of the concentrations of inorganic and organic compounds was observed only in dry years. Moreover, during wet years (as a result of flooding of the meadow) the accumulation of chemical substances is noted, due to the increase of their concentrations in ground water [20, 21]. This phenomenon was not observed during wet and dry years of ground water passing through the shelterbelt. These findings suggest high efficiency independence of atmospheric conditions of shelterbelt as biogeochemical barrier compare to the meadow.

In a study comparing the efficiency of the purification of ground water by the whole width of shelterbelt found significant higher decrease in the first 16.5 m distance than next 45.5 m. In this distance the concentrations of calcium, magnesium and mineral carbon significant declined 8-22%, 6-16%, and 15-17%, respectively (Table 5). Similar phenomenon was estimated for the migration of organic compounds. This means that the strongest decrease of the concentrations of organic compounds in ground water under shelterbelt is observed in the first 16.5 m width [24]. In particular, our earlier investigation on the efficiency of the limit of nitrogen and phosphorus in the first distance from 10 to 15 m by biogeochemical barrier such as shelterbelt are in close agreement with figures revealed for calcium, magnesium and mineral carbon [7, 15]. Further flows of ground water up to 104 m under shelterbelt resulted in an increase of all determined in dry mass. The characteristic increase of the contents of calcium, magnesium and mineral carbon along with the increase of the width of shelterbelt ranged up to 46.6%, 25.9%, 33.5%, respectively. High concentrations of all investigated compounds in ground water in this distance are connected with the change of soil's properties from mineral to mineral-organic (Table 5) [15].

Conclusions

Concerns over the environmental impact of the elements of agricultural landscapes have focused attention on the study of calcium, magnesium, mineral carbon in surface and ground water. These investigations have shown that high contents of chemical compounds migrate to ground water from cultivated fields. Ground water under cultivated fields revealed high concentrations of calcium, which means annual contents equal 373.8 mg/l. High concentrations of calcium were also measured in small water-courses. Moreover, surface water of small ponds independently of surroundings characterizes smaller contents of calcium than ground water, and ranged from 116.0 (69% less) to 176.7 mg/l Ca (53% less).

It was proved that biogeochemical barriers such as shelterbelt efficiency decrease the quantity of chemical compounds in ground water. The highest decrease of determined forms was observed in the first distance of shelterbelt (16.5 m) and ranged from 30 to 75% for dry mass, calcium from 20 to 54%, magnesium from 46 to 72% and mineral carbon from 58 to 71% was observed. Further flow of ground water up to 45.5 m width of this shelterbelt doesn't strongly impact the changes of the contents of dissolved chemical compounds. The decrease of dissolved chemical compounds in this width ranged from 8 to 22%. On the basis of all aspects it seems that the first distance (16.5 m) of shelterbelt is the most efficient for the function of biogeochemical barrier.

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References

1. BORATYŃSKI K. Agricultural chemistry. PWRiL, Warszawa, pp. 407, **1981** (In Polish).
2. HERMANOWICZ W., DOŻAŃSKA W., DOJLIDO J., KOZIOROWSKI B. Physico-chemical investigations of water and wastewater. Arkady, Warszawa, pp. 847, **1976** (In Polish).
3. KARLIK B. The susceptibility of organic matter of leached and non-leached soils to chemical oxidation. Zesz. Probl. Post. Nauk Rol. **411**, 77, **1993** (In Polish).
4. KARLIK B. Leaching of organic matter from the soils. Rocz. AR Poznań, **277,** 66, **1997** (In Polish).
5. KARLIK B., ŻYCZYŃSKA-BAŁONIAK I. Soil organic matter leaching from cultivated and uncultivated soils due to liming. INTECOL-Biulletin. **12**, 103, **1985.**

6. RYSZKOWSKI L. Ecological agriculture. Zesz. Probl. Post. Nauk Rol. **324**, 15, **1987** (In Polish).
7. RYSZKOWSKI L., ŻYCZYŃSKA-BAŁONIAK I. The limit of the spread of the pollution by biogeochemical barrier. In: Ryszkowski L., Bałazy S.(eds) Kształtowanie środowiska rolniczego na przykładzie Parku Krajobrazowego im. Gen. D. Chłapowskiego, ZBŚRiL PAN, Poznań, pp 67-80, **1998** (In Polish).
8. RYSZKOWSKI L., MARCINEK J., KĘDZIORA A. Water cycling and biogeochemical barriers in agriculture landscape. ZBŚRiL PAN, Poznań, pp. 187, **1990** (In Polish).
9. RYSZKOWSKI L., SZAJDAK L., BARTOSZEWICZ A., ŻYCZYŃSKA-BAŁONIAK I. Control of diffuse pollution by mid-field shelterbelts and meadow strips. In: Ryszkowski L. (ed.) Landscape ecology in agroecosystems management, CRS Press., Boca Raton, pp 111-143, **2002.**
10. RYSZKOWSKI L., ŻYCZYŃSKA-BAŁONIAK I., SZPAKOWSKA B. The influence of biogeochemical barriers on the expansion of non-point pollution. In: Constructed wetlands for wastewater treatment. II Międzynarod. Konf. Nauk.-Tech., Poznań, pp 147-156, **1996** (In Polish).
11. SZAJDAK L. Chemical properties of peats. In: Ilnicki P. (ed.) Peat and peatlands. Wydawnictwo Akademii Rolniczej im. Augusta Cieszkowskiego, Poznań, pp 432-450, **2002** (In Polish).
12. SZAJDAK L., MATUSZEWSKA T. Reaction of woods in changes of nitrogen in two kinds of soil. Polish J. Soil Sci. **33** (1), 9, **2000.**
13. SZAJDAK L., MEYSNER T. Influence of the shelterbelt on the containment of amino acids bound in humic acids in various kinds of soils. Polish J. Soil Sci. **35** (1), 47, **2002.**
14. SZAJDAK L., MARYGANOVA V., MEYSNER T. The function of shelterbelt as biogeoChemical barrier in agricultural landscape. Acta Agrophysica. **67**, 263, **2002a.**
15. SZAJDAK L., MARYGANOVA V., MEYSNER T., TYCHINSKAJA L. Effect of shelterbelt on two kinds of soils on the transformation of organic matter. Environ. Inter. **28** (5), 383, **2002.**
16. SZAJDAK L., ŻYCZYŃSKA-BAŁONIAK I. Influence of mild-field afforestation on the changes of organic nitrogen compounds in ground water and soil. Polish J. Environ. Stud. **11** (1), 91, **2002.**
17. SZAJDAK L., ŻYCZYŃSKA-BAŁONIAK I., JASKULSKA R. Impact of afforestation on the limitation of the spread of the pollutions in ground water and in soils. Polish J. Environ. Stud. **12** (4), 453, **2003.**
18. SZPAKOWSKA B., ŻYCZYŃSKA-BAŁONIAK I. Migration of mineral components in different ecosystems. In: Bałazy S., Ryszkowski L. (eds) Produkcja pierwotna, zasoby zwierząt i wymywanie materii organicznej w krajobrazie rolniczym., ZBŚRiL PAN, Poznań, pp 17-28, **1992** (In Polish).
19. SZPAKOWSKA B., ŻYCZYŃSKA-BAŁONIAK I. The role of biogeochemical barriers in water migration of humic substances. Polish J. Environ. Stud. **3** (2), 35, **1994.**
20. SZPAKOWSKA B., ŻYCZYŃSKA-BAŁONIAK I. Migration of dissolved humic substances in agricultural landscape. Polish J. Soil Sci. **29**, 139, **1996.**
21. SZPAKOWSKA B., ŻYCZYŃSKA-BAŁONIAK I., WAACK A. Appearance of mineral elements in ground water of agricultural landscape. In: Ryszkowski L., Wicherek S. (eds) Ecological management of countryside in Poland and France., ZBŚRiL PAN, Poznań, pp 118-127, **1997.**
22. ŻYCZYŃSKA-BAŁONIAK I., SZPAKOWSKA B. Significance of dissolved organic compounds for water migration of some ions. Part 2. Concentration of micro- and macroelements complexed with dissolved organic matter in surface freshwater in the agricultural landscape. In: Zanieczyszczenia obszarowe w zlewniach rolniczych. IMUZ, Falenty, pp 185-190, **1990** (In Polish).
23. ŻYCZYŃSKA-BAŁONIAK I., KARLIK B., SZPAKOWSKA B. The influence of liming on leaching some chemical components from soils. Post. Nauk Roln. **6**, 39, **1983** (In Polish).
24. ŻYCZYŃSKA-BAŁONIAK I., RYSZKOWSKI L., WAACK A. Migration of dissolved organic compounds with groundwater through deciduous-tree shelterbelt. In: Stan degradacji i tendencje rozwojowe gleb intensywnie użytkowanych rolniczo. Zesz. Probl. Post. Nauk Rol. **469**, 167, **1998** (In Polish).