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THE IMPACT OF THE CULTIVATION OF *Salix viminalis* L. ON CONCENTRATION OF COMPONENTS IN GROUNDWATER

WPŁYW UPRAWY *Salix viminalis* L. NA ZAWARTOŚĆ SKŁADNIKÓW W WODACH GRUNTOWYCH

Abstract: The influence of the cultivation of the common osier on sodium, calcium, potassium and magnesium concentrations in groundwater was evaluated between January 2011 and December 2012 in north-eastern Poland. The analyzed site is situated in Samławki on the premises of the Educational and Research Station in Łężany administered by the University of Warmia and Mazury in Olsztyn. Groundwater samples for chemical analyses were collected once a month from seven piezometers. Four piezometers were installed in a willow plantation: one on a hilltop, one on a slope and two varied-depth piezometers (904A – depth of 1.62 m, 904B – depth of 2.65 m) in a surface depression. The remaining three piezometers were installed for comparative purposes on arable land, in a forest on a hilltop and in a surface depression. Magnesium, calcium, sodium and potassium concentrations were determined in water samples by standard methods. The highest groundwater levels were noted in arable land (110.8 ± 53.7 cm below ground level), and the lowest levels – on the forest hilltop (572.8 ± 27.0 cm below ground level). In the willow plantation, the highest groundwater table was noted in a surface depression (272.0 ± 25.4 cm below ground level). Growing common osiers for energy significantly influenced magnesium and calcium concentrations in groundwater, which were highest on the slope of the plantation (15.1 ± 3.8 mgMg $\cdot$ dm^{-3} and 88.8 ± 26.4 mgCa $\cdot$ dm^{-3}) and on the hilltop (13.6 ± 4.5 mgMg $\cdot$ dm^{-3} and 109.1 ± 22.3 mgCa $\cdot$ dm^{-3}). The highest sodium levels in groundwater were noted on the plantation hilltop (10.2 ± 1.6 mgNa $\cdot$ dm^{-3}) and in arable land (11.5 ± 2.0 mgNa $\cdot$ dm^{-3}). Potassium concentrations in groundwater were determined by the height of the groundwater table, and they were highest on hilltops in the willow plantation (5.2 ± 4.4 mgK $\cdot$ dm^{-3}) and in the forest (4.3 ± 2.7 mgK $\cdot$ dm^{-3}).

Keywords: common osier *Salix viminalis* L., groundwater, magnesium, calcium, sodium, potassium

The production of biomass for energy, including in willow and osier plantations, is becoming an important part of modern agricultural systems. Energy willows can be grown throughout Poland, and the main factors that limit their cultivation are water

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deficit and nutrient deficiency, mainly low supply of nitrogen as a yield-forming factor. Willows are a highly versatile tree species that may be used for the manufacture of bioenergy [1]. Conventional agricultural practices cause soil salinification, which reduces crop yield due to the accumulation of soluble inorganic salts in soil. The above leads to a rise in magnesium, calcium, sodium and potassium concentrations in the soil solution that exceed the assimilative capacity of plants. Salinification also reduces the availability of water and nutrients in soil [2]. Plants resistant to pollution are introduced to arable land to prevent excessive salinification. The common osier (*Salix viminalis* L.), a species of willow, is tolerant to pollution, and it is used as a pioneer species in biological purification projects. The cultivation of energy crops can significantly influence mineral concentrations in groundwater. Poland is characterized by low quality and quantity of water resources, and energy willow plantations contribute to the protection of the country's meager water reserves. Low precipitation, high surface evaporation and uneven distribution of precipitation and evaporation contribute to a further reduction in water resources. Human activities also exert a negative impact on the availability of fresh water [3].

Materials and methods

The objective of this study was to determine the influence of the cultivation of the common osier (*Salix viminalis* L.), a species of willow, on sodium, calcium, magnesium and potassium concentrations in groundwater. The experiment was carried out between January 2011 and December 2012 in Samławki, Region of Warmia and Mazury, approximately 80 km from the city of Olsztyn, on the premises of the Educational and Research Station of the University of Warmia and Mazury in Olsztyn. Piezometers were installed in the willow plantation at points that represented different land relief features characteristic of lakelands. One piezometer was installed on the hilltop (902), one on the slope (903), and two in a surface depression (904A – depth of 1.62, 904B – depth of 2.65 m). Three piezometers were installed for comparative purposes: one in arable land in the direct vicinity of the willow plantation (905), one on the hilltop in the forest (906) and one in a surface depression in the forest (907). Water samples for chemical analysis were collected once a month with the use of the GIGANT submersible pump. Magnesium, calcium, sodium and potassium concentrations in water samples were determined in the laboratory of the Department of Land Reclamation and Environmental Management (Mg using method of yellows titanium – visual method and Ca, Na and K using Atomic Absorption Spectrometry). The Ca:Mg ratio was calculated as a ratio of concentration of calcium and magnesium. The height of the groundwater table was determined with a whistle unit.

The results of chemical analyzes of groundwater was respondents statistical analyzes in *STATISTICA PL 10.0*, was determined position measurement (mean, median) and dispersion (variance, variations, and skewness). Was using parametric tests (Shapiro Wilk test) and nonparametric (U Manna-Whitney'a test) at the significance level $\alpha = 0.05$ was significanced of differences was examined properties of the tested groundwater and verified the significance of the differences in values and normality in relation to the growing and nongrowing season and catchment management (willow plantation and points of comparison).

Results and discussion

The mineral content of groundwater is determined by the movement of minerals into the soil profile. The rate of infiltration is influenced by the physicochemical properties of soil, land-use type, location and plant cover [4]. Soil moisture content is determined by rainfall intensity and distribution, surface evaporation, groundwater levels, which can be influenced by land improvement measures (drainage, irrigation), and land-use type. Moisture content affects the movement of minerals into the soil profile and their distribution in groundwater [5]. In the present study (observations from January 2011 to December 2012), the highest groundwater levels in the willow plantation were noted in a surface depression (904A – 133 m below ground level; 904B – 124 cm below ground level in the winter half-year to 130 cm below ground level in the summer half-year on average), and the lowest groundwater table was reported on the hilltop (from 372 cm below ground level in the summer half-year to 334 cm below ground level in the winter half-year on average), regardless of season (Fig. 1).

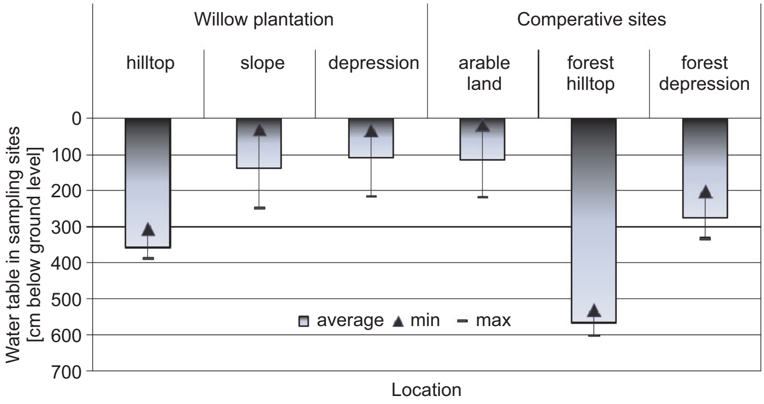

Fig. 1. Groundwater table in sampling sites
Key: Willow plantation: 1 – hilltop; 2 – slope; 3 and 4 – surface depression. Comparative sites: 5 – arable land; 6 – hilltop in the forest; 7 – surface depression in the forest.

The lowest groundwater table in the willow plantation and in comparative sites was observed on the hilltop in the forest (from 574 cm below ground level in summer to 568 cm below ground level in winter on average). Groundwater levels were highest in arable land (116–105 cm below ground level). The height of the water table influenced soil moisture levels.

The highest water table (572.8 m below ground level) was determined in sampling site 906 on the hilltop in the forest. Ground water levels in the above location differed significantly from the remaining sampling sites, excluding that on the hilltop of the willow plantation (363.54 m below ground level), which could be attributed to similarities in land relief (Fig. 2).

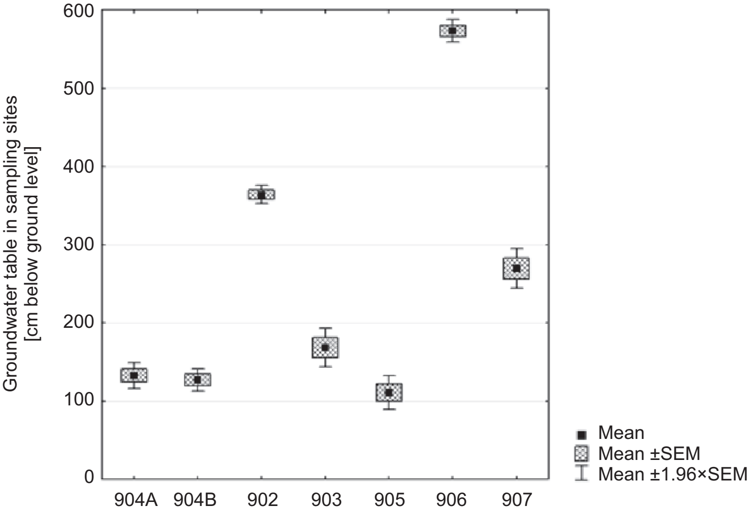

Fig. 2. Groundwater levels determined in 2011–2012 in sampling sites
Key: Willow plantation: 902 – hilltop; 903 – slope; 904A and 904B – surface depression. Comparative sites: 905 – arable land; 906 – hilltop in the forest; 907 – surface depression in the forest.

The highest fluctuations in soil moisture content are noted in arable land and forests characterized by shallow subsoil water. The variations in soil moisture content are minimized with an increase in groundwater table depth. Groundwater levels significantly influence the active soil layer, the processes that take place inside that layer and, consequently, the development of plant root systems [3].

Calcium and magnesium are essential for the growth and development of plants, and those macronutrients are taken up by plants in large quantities. Magnesium is a component of plant chlorophyll, and it activates various enzymatic reactions, can mitigate the effects of phytotoxicity [6]. Calcium controls water intake and metabolic processes, and it also regulates the accumulation of soil colloids Sodium and potassium influence vital life processes in plants. Potassium is responsible for synthesis and respiration processes, and it regulates the water balance in plant tissues.

The magnesium content of the analyzed groundwater samples was determined mainly by the type of land use in the catchment, land relief features and the levels of plant-available magnesium, which varied on a seasonal basis. The lowest magnesium concentrations (3.6 mg · dm^{-3} on average) were noted in a surface depression in the forest, and they differed significantly from the remaining sampling sites (Fig. 3). Magnesium concentrations in groundwater on the hilltop in the forest (9.2 mg · dm^{-3} on average) were similar to those reported in a surface depression in the willow plantation (9.3–9.5 mg · dm^{-3}) (Fig. 3).

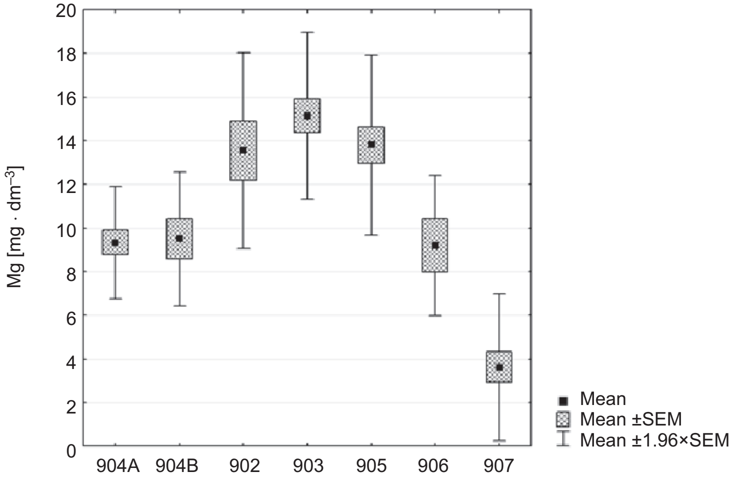

Fig. 3. Magnesium concentrations in groundwater determined in 2011–2012 in sampling sites
Key: Willow plantation: 902 – hilltop; 903 – slope; 904A and 904B – surface depression. Comparative sites: 905 – arable land; 906 – hilltop in the forest; 907 – surface depression in the forest.

The highest magnesium concentrations were noted in groundwater samples collected on the slope of the willow plantation (15.1 mg · dm^{-3} on average), and they were 1.3 mg · dm^{-3} higher than those reported in arable land. The lowest magnesium content (1.2 mg · dm^{-3}) was observed in groundwater sampled from the plantation hilltop. In both the summer and winter half-years and in both years of the study on average, similar magnesium levels were noted in groundwater samples from the hilltop and the slope of the willow plantation and from arable land. Magnesium concentrations noted in a surface depression in the plantation were similar to those reported on the hilltop in the forest. In comparison with the willow plantation, much greater differences in the magnesium content of groundwater were observed in the forest between sampling sites on the hilltop and in a surface depression. Magnesium levels on the hilltop were three-fold higher than in the surface depression, which could be attributed to higher assimilation of magnesium by rapidly growing forest plants in the depression. Variations were also reported in the willow plantation where magnesium concentrations differed by 42–48 % between sampling sites. Magnesium levels in groundwater were higher in the winter half-year when this mineral was not accumulated or when its uptake was limited. A high water table limits the thickness of the active soil layer and the root zone, whereas low groundwater levels support soil aeration and the formation of a healthy root system [3]. The greatest variations in the magnesium content of groundwater between the seasons were observed in the forest and in arable land, where magnesium concentrations were approximately 30 % and 20 % higher in winter, respectively. According to Burzyńska [7], the average magnesium content of subsoil water in grasslands reached 11.80 mg Mg · dm^{-3}. In the cited study, the rate of magnesium uptake by plants was determined mainly by the species composition of meadow vegetation, soil pH and the ratio of magnesium to the accompanying cations.

Soil pH significantly affects the magnesium content of subsoil water. Soil acidity decreases when agricultural production is terminated, which supports the migration of magnesium to shallow subsoil water. Similar trends were reported by Koc et al [4] regardless of the type of land use. Soil acidification processes (acid rain, nitrification) can contribute to the leaching of magnesium from soil to groundwater.

During both years of the study (2011 and 2012), the highest calcium concentrations (109.5 mg · dm^{-3} on average) were observed in groundwater sampled from the hilltop and slope (88.8 mg · dm^{-3}) of the willow plantation and the lowest – in a surface depression in the forest (12.8 mg · dm^{-3}). Calcium levels in the above location differed significantly from those noted in the remaining sampling sites (Fig. 4). The average calcium concentration values were similarly distributed. Similarly to magnesium, the concentrations of calcium were much lower in groundwater sampled from a surface depression due to limited water availability. Greater variations in groundwater levels were noted in arable land than in the forest [8].

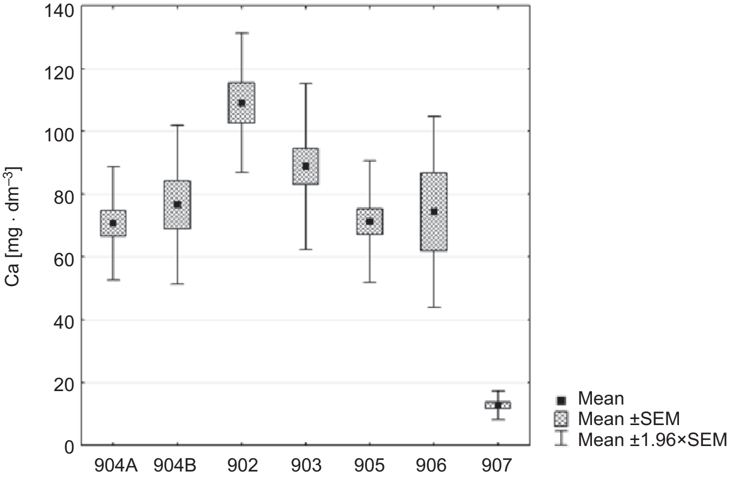

Fig. 4. Calcium concentrations in groundwater determined in 2011–2012 in sampling sites
Key: Willow plantation: 902 – hilltop; 903 – slope; 904A and 904B – surface depression. Comparative sites: 905 – arable land; 906 – hilltop in the forest; 907 – surface depression in the forest.

In groundwater samples collected from the willow plantation and arable land, calcium concentrations were lower in winter, whereas significantly higher levels of calcium were noted in the forest in summer.

The Ca:Mg ratio was similar in groundwater sampled from the willow plantation and the forest (7.25 and 7.14, respectively), but it was somewhat narrower (5.2) in arable land. According to Orzepowski and Pulikowski [9], the Ca:Mg ratio of groundwater in arable land ranges from 2.7 to 6.9.

In this study, the highest (11.5 and 10.2 mg · dm^{-3}) were noted in arable land and hilltop of willow plantation. The lowest (3.6 mg · dm^{-3}) sodium concentrations were noted in surface of depression in the forest. The sodium content of groundwater in the willow plantation ranged from 5.6 mg · dm^{-3} in surface depression 904A, 8.5 mg · dm^{-3} on the slope of plantation, to 13.2 mg · dm^{-3} on the hilltop. The average sodium content of groundwater in a surface depression in the willow plantation was significantly lower in comparison with the remaining sampling sites (Fig. 5), which could be attributed to differences in land-use type and the rate of sodium uptake by forest plants.

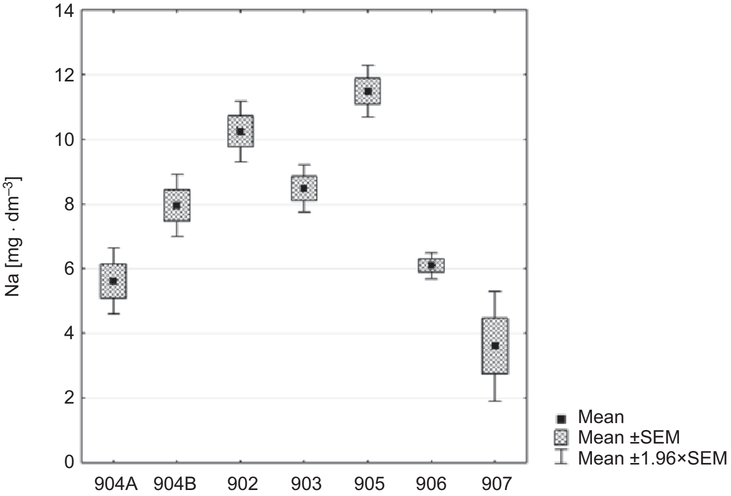

Fig. 5. Sodium concentrations in groundwater determined in 2011–2012 in sampling sites
Key: Willow plantation: 902 – hilltop; 903 – slope; 904A and 904B – surface depression. Comparative sites: 905 – arable land; 906 – hilltop in the forest; 907 – surface depression in the forest.

In both years of the study, the average sodium content of the analyzed groundwater samples were somewhat higher in arable land than in the willow plantation (regardless of land relief) and two- to three-fold higher than in the forest. The above could point to progressing salinification of groundwater in arable land, which could be attributed to intensive farming (loose topsoil layer) and mineral fertilization. In view of the average summer and winter values, the highest average sodium concentrations in groundwater were reported in arable land (from 11.3 mg · dm^{-3} in the summer half-year to 11.6 mg · dm^{-3} in the winter half-year). Relatively high sodium levels were also observed on the hilltop in the willow plantation (8.6–10.8 mg · dm^{-3}), and higher values were noted in summer. In the plantation, the lowest sodium concentrations in groundwater (5.6 mg · dm^{-3} on average) were determined in a surface depression (904A), and the lowest sodium levels in the entire analyzed area (3.6 mg · dm^{-3}) were noted in a surface depression in the forest.

According to Orzepowski and Pulikowski [9], mineral concentrations in groundwater are determined by soil type, and they are increased by the inflow of pollutants from farmland. In the cited study, the highest sodium concentrations (109.7 mgNa · dm^{-3}) were not noted on arable land (black/clayey soil and silty clay), but in an area where farm effluents constituted a point source of pollution.

Cymes and Szymczyk [5] reported lower concentrations of magnesium, calcium and sodium in groundwater in arable land than in grasslands. The analyzed minerals are more readily assimilated by plants in arable land due to higher soil aeration and more supportive air-water relationships. The mineral content of groundwater is also significantly influenced by land relief, which affects the movement of elements in soil and their uptake by plants. Water-soluble minerals migrate towards the outflow of the water source, which contributes to nutrient deficiency in soils and groundwater on hilltops. Groundwater resources on slopes and in surface depressions are more abundant in minerals. In areas with better access to water, nutrients are more available for plants, whereas water deficits, which are more frequently noted on slopes than in surface depressions, can lower the rate of mineral accumulation and increase nutrient concentrations in groundwater [5].

Potassium levels in the analyzed groundwater samples ranged from 1.8 ± 0,8 mg · dm^{-3} in surface depressions in the willow plantation and in arable land to 5.2 ± 4.4 mg · dm^{-3} on the hilltop in the plantation. Potassium concentrations in the latter location differed significantly from the remaining sampling sites, excluding the forest hilltop (Fig. 6). The lowest potassium content was determined in groundwater sampled from piezometers installed in a ground depression in the willow plantation (1.8 ± 0.8 mg · dm^{-3} and 2.0 ± 0.7 mg · dm^{-3}, on average). The above can probably be attributed to the migration of potassium into the soil profile and outside the root zone, which significantly impaired potassium accumulation, in particular in water-deficient sites.

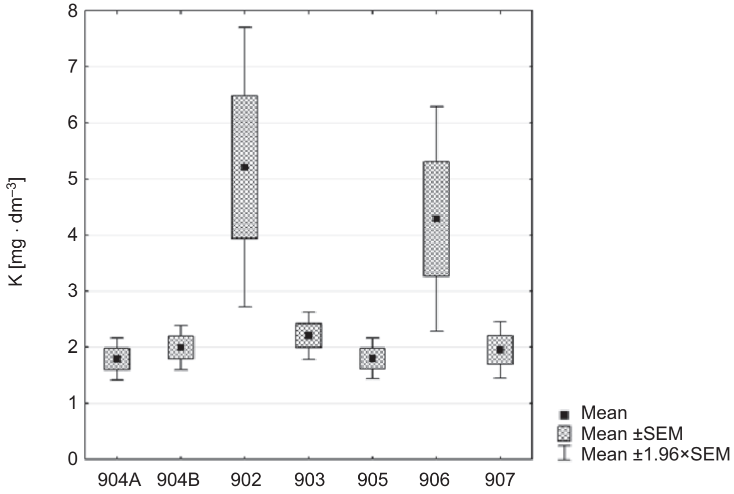

Fig. 6. Potassium concentrations in groundwater determined in 2011–2012 in sampling sites
Key: Willow plantation: 902 – hilltop; 903 – slope; 904A and 904B – surface depression. Comparative sites: 905 – arable land; 906 – hilltop in the forest; 907 – surface depression in the forest.

The correlations between potassium concentrations vs. land relief and land-use type were somewhat different when analyzed across seasons. Potassium levels on the hilltop and on the slope in the willow plantation and in arable land were significantly higher in the summer half-year. A reverse trend was noted in the forest and in a surface depression in the plantation.

Based on the Shapiro-Wilk test, it was found that all the indicators that have been identified in the examined surface waters were characterized by asymmetric compared to the average, $p < 0.05$ (course inconsistent with the Gaussian curve – normal distribution, Table 1).

Table 1

Statistical analyzes of chemical indicator in groundwater

Parameter	Level [cm]	Mg [mg · dm^{-3}]	Ca [mg · dm^{-3}]	Na [mg · dm^{-3}]	K [mg · dm^{-3}]
Mean ± SEM	238.6 ± 152.3	10.8 ± 5.6	67.8 ± 32.3	7.7 ± 3.7	2.5 ± 2.1
Variance	23199.4	30.9	1314.4	13.6	4.4
Median	203.0	11.1	72.4	8.2	1.8
Varibility	63.8	51.6	53.5	47.6	84.7
Skewness	1.0	–0.1	–0.2	0.00	4.0
Normal distribution – probability p-test					
Shapiro-Wilk test	0.000	0.004	0.000	0.004	0.000
Determine significance of difference between means					
U Manna Whitneya (1)*	0.066	0.494	0.121	0.311	0.926
U Manna Whitneya (2)*	0.038	0.001	0.000	0.421	0.038

* (1) – U Manna Whitney test used to analyzes to difference between means in growing and no growing seasons; (2) – U Manna Whitney test used to analyzes to difference between means In groundwater on willow plantation and comparative points.

During the statistical analysis model statistics, which was equivalent to the non-parametric Student's t-test, which was the U Manna-Whitney test was formulated hypothesis for H_0: means values of the tested ingredients contained groundwater during the growing season and non growing aren't different significantly (m1 = m2) (1), as well as: the average values of the studied ingredients contained in the groundwater located under the willow plantation and comparison points aren't different significantly (m1 = m2) (2) to the alternative hypothesis (H1): the average values of the studied ingredients contained in groundwater in growing and non growing season aren't equal (m1 ≠ m2) (1) and the average values of the studied ingredients contained in the groundwater beneath the willow plantation and benchmarks aren't equal (m1 ≠ m2) (2).

On this basis, it was found that the differences between the concentrations of the components under consideration in all periods studied groundwater did not different significantly, in turn, was significantly statistical difference between the mean values of the analyzed components in the groundwater under the plantation of willow and comparative points at the significance level $\alpha = 0, 05$ (Table 1). This demonstrates of the significant impact of catchment management, including willow cultivation for energy purposes in the development of the components of magnesium, calcium, sodium, potassium in groundwater.

The mineral content of groundwater was significantly influenced by the type of land use in the catchment and fertilization. According to Burzynska [7], nitrogen fertilization (calcium and ammonium nitrate) affected potassium levels in soil and groundwater. Czajkowska [10] demonstrated correlations between the potassium content of groundwater and season, where potassium concentrations were higher in fall (13.8 mg · dm^{-3} in October and 11.7 mg · dm^{-3} in summer) regardless of soil porosity and aeration. The above could result from the fact that potassium fertilizers are applied in late summer and early spring and that potassium ions migrate easily in agricultural catchments.

The mineral content and, consequently, the quality of groundwater is determined by a combination of natural processes and factors, many of which are human-induced. The chemical composition of groundwater varies in space and time [11].

Conclusions

1. Magnesium, calcium, sodium and potassium concentrations in groundwater were determined by land-use type, land relief and weather conditions that influenced mineral accumulation and the movement of water and minerals into the soil profile.

2. The mineral, calcium, sodium and potassium content of groundwater sampled from a willow plantation was determined by the availability of water in the growing season. Periodic water deficits on the hilltop and on the slope lower nutrient availability for plants, which increases magnesium, calcium, sodium and potassium concentrations in groundwater.

3. Under similar water availability to plants in arable land and in the willow plantation (surface depression), the cultivation of the common osier decreases magnesium, calcium, sodium and potassium concentrations in groundwater.

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WPŁYW UPRAWY *Salix viminalis* L. NA ZAWARTOŚĆ SKŁADNIKÓW W WODACH GRUNTOWYCH

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Abstrakt: Badania nad wpływem uprawy wierzby krzewiastej na jakość wód gruntowych pod względem zawartości sodu, wapnia, potasu i magnezu realizowano od stycznia 2011 roku do grudnia 2012 roku na terenie Polski północno-wschodniej. Obiekt badawczy znajduje się na gruntach należących do Stacji Dydaktyczno-Badawczej Uniwersytetu Warmińsko-Mazurskiego w Olsztynie z siedzibą w Łężanach – obiekt Samławki. W celu analiz chemicznych wody gruntowe pobierano systematycznie raz w miesiącu z zainstalowanych 7 piezometrów. Cztery z nich zostały zlokalizowane na plantacji wierzby: po jednym na wierzchowinie, stoku oraz dwa o zróżnicowanej głębokości (904A – 1,62 m głębokości i 904B – 2,65 m głębokości) w obniżeniu terenu. Trzy pozostałe punkty stanowiły obiekty porównawcze i umieszczono je: na gruncie ornym oraz w lesie na wierzchowinie i w obniżeniu terenu). W pobranych wodach oznaczono standardowymi metodami stężenia magnezu, wapnia, sodu i potasu. Na podstawie przeprowadzonych obserwacji można stwierdzić, że najwyższy poziom zalegania wód gruntowych stwierdzono na gruntach ornych (110,8 ± 53,7 cm p.p.t.), z kolei najniższy występował na wierzchowinie w lesie (572,8 ± 27,0 cm p.p.t.). Na terenie plantacji najwyższe stany wód były charakterystyczne dla punktu w obniżeniu terenu (272,0 ± 25,4 cm p.p.t.). Uprawa wierzby wiciowej na cele energetyczne w istotny sposób wpłynęła na zawartość w wodach gruntowych magnezu i wapnia, które występowały w największych stężeniach w wodzie gruntowej na stoku plantacji (15,1 ± 3,8 mgMg · dm^{-3} oraz 88,8 ± 26,4 mgCa · dm^{-3}) oraz na wierzchowinie (13,6 ± 4,5 mgMg · dm^{-3} i 109,1 ± 22,3 mgCa · dm^{-3}). Największe koncentracje sodu również występowały w wodzie gruntowej wierzchowinie plantacji (10,2 ± 1,6 mgNa · dm^{-3}) oraz na gruntach ornych (11,5 ± 2,0 mgNa · dm^{-3}). Stężenia potasu w wodach gruntowych uzależnione były od poziomu zalegania, co potwierdzają najwyższe koncentracje w punktach zlokalizowanych na wierzchowinie zarówno na plantacji wierzby (5,2 ± 4,4 mgK · dm^{-3}), jak i w lesie (4,3 ± 2,7 mgK · dm^{-3}).

Słowa kluczowe: wierzba krzewiasta, *Salix viminalis* L., wody gruntowe