J. Elem. s. 17–29 DOI: 10.5601/jelem.2014.19.1.596

PHYSICOCHEMICAL PROPERTIES OF SURFACE SOIL LAYER AFTER THE FLOOD IN THE MIDDLE VISTULA RIVER VALLEY

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Abstract

Environmental studies conducted after the 2010 flood in the middle Vistula River Valley focused on assessment of the physicochemical properties of soil (0-20 cm) sampled from horticultural plantations (2493 samples). Soil pH_{KCl} as well as the content of available P, K and Mg forms were determined. Selected samples (48) were analysed for the content of heavy metals (Cu, Zn, Cd, Pb, Cr, Ni, As, Hg), mineral N, $S\text{-}SO_4$, salinity and dry mass. The tested soil pH ranged from acid to neutral; the phosphorus content was in the average range, while the content of available potassium was 161.0 mg K kg^{-1} and that of available magnesium exhibited the value of 160.5 mg Mg kg^{-1}. The mean value of pH_{KCl} and available P were not elevated in the flooded soils versus the same soils before the flood, while the available K and Mg were higher. The content of mineral nitrogen and sulphate sulphur as well as the salinity level were only slightly dependent on the soil agronomic category and soil pH. The content of heavy metals in the soil was higher than before the flood, but did not exceed natural values. The analyses did not demonstrate any significant deterioration of the physicochemical parameters of soils after the 2010 flood, which could negatively affect the quality and yield of cultivated fruit trees and shrubs.

Keywords: flood, soil physicochemical properties, soil agronomic category, heavy metals, macroelements.

WŁAŚCIWOŚCI FIZYKOCHEMICZNE POWIERZCHNIOWEJ WARSTWY GLEBY PO POWODZI W DOLINIE ŚRODKOWEJ WISŁY

Abstrakt

W badaniach środowiskowych przeprowadzonych po powodzi, która wystąpiła w 2010 r. w Dolinie Środkowej Wisły, oceniano właściwości fizykochemiczne gleb (0-20 cm) pobranych

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spod plantacji sadowniczych (2493 próbki). Oznaczono w nich pH_{KCl} oraz zawartość przyswajalnych form P, K i Mg. W wybranych 48 próbkach oznaczono dodatkowo zawartość metali ciężkich (Cu, Zn, Cd, Pb, Cr, Ni, As, Hg), N-mineralny, $S-SO_4$, zasolenie i suchą masę. Odczyn badanych gleb mieścił się w zakresie od kwaśnego do obojętnego, zasobność fosforu przyswajalnego była przede wszystkim średnia, zawartość potasu przyswajalnego wynosiła 161.0 mg K kg^{-1}, magnezu przyswajalnego 160.5 mg Mg kg^{-1}. W glebach po powodzi, w porównaniu z glebami sprzed tego zdarzenia, nie stwierdzono podwyższonego pH_{KCl} i zawartości P-przyswajalnego, ale odnotowano wyższą zawartość K i Mg przyswajalnego. Zawartość azotu mineralnego, siarki siarczanowej i zasolenia w niewielkim stopniu zależała od kategorii agronomicznej i odczynu gleby. Zawartość metali ciężkich w glebie była wyższa niż przed powodzią, ale nie przekroczyła zawartości naturalnych. Wykazano, że po powodzi z 2010 r. nie stwierdzono znaczącego pogorszenia właściwości fizykochemicznych gleb, które mogłyby negatywnie oddziaływać na jakość i plonowanie uprawianych roślin, w tym drzew i krzewów owocowych.

Słowa kluczowe: powódź, właściwości fizykochemiczne gleby, kategoria agronomiczna gleby, metale ciężkie, makroelementy.

INTRODUCTION

Floods occur in various parts of the world, including Poland, causing substantial economic losses and contributing to changes in various environmental elements, e.g. in soil (EULENSTEIN et al. 1998, KUCHARZEWSKI, NOWAK 2000, NAGEL et al. 2003, ŠERÁ et al. 2008).

Heavy rainfalls on May 14-18 and June 1-2, 2010 in the upper Vistula River basin resulted in two flood waves, which caused substantial damage in the agricultural environment of the Lublin Province (BEDNAREK et al. 2011). The first wave in the Lublin Province flooded 23 villages and approximately 90% of the Wilków Commune. Admittedly, May 2010 was extremely wet across all the country. The highest level of monthly precipitation was reported in Bielsko-Biała (511.5 mm; 509% of the station's norm) and in Kraków (302.4 mm; 130.8% of the long-term norm) (*Bulletin* ... 2010*a*). In June that year, the highest monthly precipitation level was recorded in Nowy Sącz (193.9 mm; 186,1% of the norm) and Tarnów (179.4 mm; 172.5% of the norm). In Warsaw, the monthly rainfall sum was 86.8 mm (121.9% of the long-term norm) (*Bulletin* ... 2010*b*). The flood caused considerable loss in agriculture and horticulture (EULENSTEIN et al. 1998, KUCHARZEWSKI, NOWAK 2000). The largest damage to horticultural plantations was reported from the Sandomierz Valley and Wilków in the Lublin Region. In communes situated in the Vistula valley near Sandomierz, orchards and blueberry plantations were flooded up to the height of 1.5 to 4 m twice or thrice in several weeks. In Wilków Commune, floodwater covered 1400 ha of horticultural plantations for several weeks. Apple orchards, which constitute 70% of horticultural plantations, prevailed in all the flooded regions (ZIELIŃSKI 1997).

The aim of the study was to assess physicochemical properties of soils sampled from horticultural areas in the middle Vistula River valley in the Lublin Region after the 2010 flood.

MATERIAL AND METHODS

In July and August 2010, soil (0-20 cm) was sampled from orchards flooded in May and June that year. Alluvia deposited during the flooding were sampled together with the soil. In total, 2493 samples were taken, most from the communes of Wilków (1365) and Łaziska (951). 121 samples were taken in and around Józefów nad Wisłą, 32 in Janowiec, 20 in Puławy and 4 in Opole Lubelskie. About 47% of the sampled soils belonged to the agronomic category composed of medium-heavy soils (containing 20-35% of particles with diameter <0.02 mm), 40% were heavy soils (>35% of particles with diameter <0.02 mm), 10% – light soils (10-20% of particles with diameter <0.02 mm), 2% – very light soils (up to 10% of particles with diameter <0.02 mm), and 1% represented organic soils. The number of the samples depended on the surface area that had been flooded and presence of orchards in a given region. Some basic soil properties were determined, i.e. the agronomic category, pH_{KCl}, available forms of phosphorus, potassium, and magnesium; also, the K:Mg ratio was calculated for the sake of rational soil fertilisation with these chemical elements (Sadowski et al. 1990). In order to assess more thoroughly the effect of flooding on soil properties, some samples were additionally analysed for dry mass, mineral nitrogen, $S\text{-}SO_4$, salinity as well as the levels of copper, zinc, cadmium, lead, chromium, nickel, arsenic and mercury. These additional chemical analyses were performed on soil samples from orchards located in the following villages: Wilków – 3, Las Dębowy – 4, Braciejowice – 4, Dobre – 1, Zastów Karczmiska – 2, Niedźwiada Duża – 1, Zagłoba – 9, Kąty – 5, Zakrzów – 9, Kępa Solecka – 6, Machów – 1, Kępa Chotecka – 1, Kol. Wilków – 1, and Zastów Polanowski – 1. In total, additional analyses were performed on 48 soil samples, which had been taken according to the criterion of an additional environmental risk caused by flooding, e.g. stores of mineral and natural fertilizers or pesticides. The chemical analyses were carried out in an accredited laboratory of the Regional Chemical-Agricultural Station in Lublin. The following were determined: soil agronomic category, pH in 1 mol KCl dm^{-3}, phosphorus and potassium with the Egner-Riehm method (DL), magnesium with the ASA method after extraction from soil with 0.0125 mol $CaCl_2$ dm^{-3}, mineral nitrogen in its nitrate and ammonium forms determined colorimetrically (Dresler et al. 2011), sulphate sulphur with the nephelometric method, salinity, dry mass and trace elements with the ASA method after mineralization in a mixture of concentrated HCl and HNO_3 (3:1) acids (*A catalogue of methods* ... 2011). The results were analysed statistically, employing one-way non-orthogonal analysis of variance, with the Tukey's confidence semi-intervals (p = 0.05). Moreover, correlations between some soil properties were calculated. Since pH_{KCl} showed a nearly normal distribution, arithmetic means of this index were calculated (Gruba et al. 2010). For statistical calculations and graphic representation of the correlations between the agronomic soil

Table 1

Soil pH, content of available macroelements and the K:Mg ratio in soil (0-20 cm)

Region of soil sampling	*n*	pH_{KCl}	P	K	Mg	K:Mg	Agronomic category
			$(mg\ kg^{-1})$				
Józefów	121	6.6ns**	71.7a*	177.2*ab*	78.8*e*	3.13*c*	2.25*d*
Janowiec	32	6.7ns	63.2*ab*	135.1*ab*	173.8*abcd*	0.87*ab*	2.88*c*
Łaziska	951	5.6ns	57.5*b*	183.6*b*	171.0*cd*	1.21*b*	3.22*a*
Opole Lub.	4	5.4ns	50.0*ab*	179.8*ab*	216.3*ab*	0.85*ab*	3.75*ab*
Puławy	20	5.7ns	47.6*ab*	125.5*ab*	157.4*ab*	0.99*ab*	3.10*abc*
Wilków	1365	6.0ns	66.0*a*	164.8*a*	165.4*ac*	1.07*a*	3.40*b*
Total	2493	6.0ns	59.3	161.0	160.5	1.35	3.1

n – sample number, * – homogeneous groups, ** – not significant

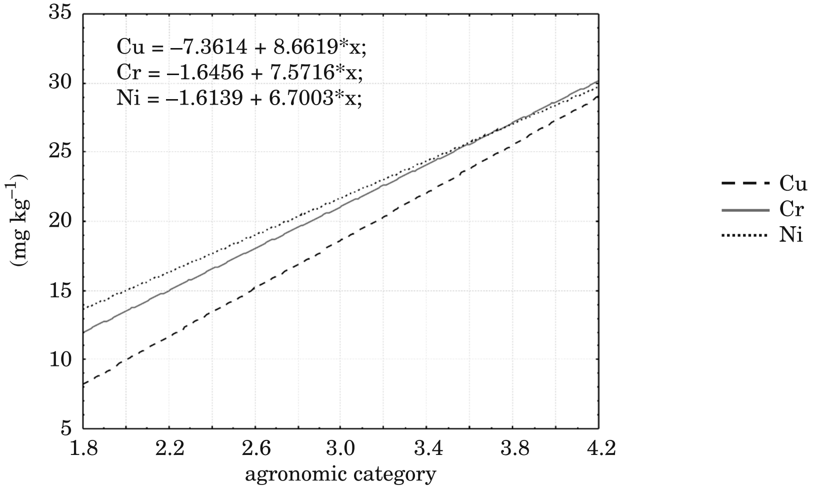

Fig. 1. Correlation between the content of Cu, Cr and Ni in soil versus the agronomic category

category and soil content of Cu, Cr and Ni, very light soils (very coarse textured) were assigned value 1, light – 2, medium – 3 and heavy ones – 4 (Table 1, Figure 1).

RESULTS AND DISCUSSION

The soil pH in the studied area was varied: from acidic (pH_{KCl} 5.5), slightly acidic (pH_{KCl} 5.6-6.0) to neutral (pH_{KCl} 6.6-6.7) – Table 1. Organic and very light soils had the highest acidity with the pH value of 5.1 and 5.2, respectively. The pH value in light, medium, and heavy soils was slightly

Table 2

Soil pH, content of available macroelements and the K:Mg ratio in soil (0-20 cm) in relation to the agronomic category

Agronomic category	n	pH_{KCl}	P	K	Mg	K:Mg
			$(mg\ kg^{-1})$			
Heavy	994	5.9ns**	54.2_b_*	161.4_a_	190.3_d_	0.88_a_
Light	255	5.9ns	71.1_a_	166.2_ab_	92.3_b_	2.25_c_
Medium	1173	5.9ns	68.7_a_	184.5_b_	160.4_c_	1.22_b_
Very light	45	5.2ns	51.2_ab_	107.2_c_	48.4_a_	2.64_d_
Organic soil	26	5.1ns	262.4_c_	161.0_abc_	338.4_e_	0.53_a_
Total	2493	5.6ns	64.9	171.7	165.2	1.50

_n_ – sample number, * – homogeneous groups, ** – not significant

acidic, i.e. 5.9 (Table 2). After the flood in the environs of Wrocław, the average increase in soil acidity was from pH 5.6 to pH 5.1 (Kucharzewski, Nowak 2000). On the German side of the Odra River, the pH declined on average from 6.2 to 5.9 (Eulenstein et al. 1998). A possible cause of the pH decrease may have been the anaerobic fermentation processes induced by soil waterlogging (Eulenstein et al. 1998). In turn, investigations conducted in flooded areas in the Czech Republic revealed more neutral values in most samples than those found before the flood (Šerá et al. 2008); interestingly, the pH changes did not exert unfavourable effects on the riparian ecosystem. In 2007, an assessment of floodplain soils in the middle Elbe River area showed that their pH ranged between 4.3 and 7.9 (Zimmer et al. 2011). In a study on flooded rice soils by Fageria et al. (2011), it was found that the pH of acidic soils increased and that of alkaline soils declined. Soil sampled from a Mexican mangrove forest analysed in 2009 was characterized by a high pH (Cerón-Bretón et al. 2011). Areas that had been flooded more frequently and intensively contained more sulphur. Investigations carried out in three locations in a floodplain of the mouth of the Dovey River in Wales, the UK, showed that a 2.3- to 3.5-fold increase in precipitation was accompanied by an increase in soil salinity and pH. Depending on the location, the salinity gradient was significant, reaching a 13-fold difference. A similar gradient was found for soil pH (Dausse et al. 2012). One should take into consideration the fact that soil pH may control mobility of heavy metals, which grows with a declining pH (Nagel et al. 2003). Furthermore, the investigations presented in the aforementioned paper provide evidence that the content of easily soluble heavy metals in calcareous soils is highly dependent on pH.

In the majority of soils, the content of available phosphorus was on a moderate level relative to the limit values, being high in only one location (Table 1). It was significantly higher in the soils from Józefów and Wilków, than in the soil from Łaziska, where it was significantly lower than elsewhere. The significance of the differences may have been related to the amount of phosphorus fertilizers applied and the number of samples taken (Table 1).

In very light and heavy soils, the content of this element was moderate, in light and medium soils – high, and in organic soils – very high (Table 2). In organic soils, its content was significantly higher than in mineral soils, and in light and medium soils, it was higher than in heavy soils.

The content of available potassium in the soils was fairly varied and ranged from 125.5 to 183.6 mg K kg^{-1} (Table 1). Its content was high in very light, light and medium soils, and moderate in heavy soils (Table 2). The content of available magnesium in the soils sampled from the particular regions was even more diverse. The lowest amount of this element was detected in the soils sampled from Józefów (78.8), and the highest appeared in the soils taken from Opole Lubelskie (216.3 mg Mg kg^{-1}). The content of this element in very light soils was high, and very high in light, medium and heavy soils. The broadest K:Mg ratio was found in the soils from Józefów nad Wisłą (3.13). In the soils sampled from the other locations it was close to 1. The narrowest ratio was characteristic for organic soils (0.53), and the broadest one – for very light soils (2.64). The magnitude of these ratios should be regarded as proper, never exceeding the threshold of 3.5 (SADOWSKI et al. 1990). EULENSTEIN et al. (1998) conducted investigations in flooded areas near the Odra River and, in most cases, demonstrated a slight decline in the available P and Mg content as well as an increased level of K in soil. The authors claimed that the increased K content may have been due to the flooding of a fertilizer storage and transfer of solved fertilizers into flood water. The changes in the P, Mg and K content were within the ranges of variation caused by fertilization. Importantly, the flood did not change significantly the nutrient content in the soil.

The analyses performed before the flood (2007-2009, n = 511) showed the following means of the soil parameters: pH_{KCl} – 6.0 (5.6-6.5); the content of available phosphorus – 61.6 (49.5-76.5) mg P kg^{-1}, potassium – 137.2 (94.5-210.7) mg K kg^{-1} and magnesium – 85.8 (35.4-120.7) mg Mg kg^{-1}. These results did not differ significantly from the pH_{KCl} values and available phosphorus content after the flood, whereas the levels of available potassium and magnesium, in particular, were higher. Potassium and magnesium may have been relatively easily washed out of soil, or else these elements may have been imported into the studied area with the flood wave.

GĄSIOR et al. (2003) found that long-term persistence of flood waters resulted in a several-fold increase of concentration of the basic element forms, i.e. calcium to 3.7 g kg^{-1}, magnesium to 5.4 g kg^{-1} and potassium to 9.5 g kg^{-1}. CHODAK and PERLAK (1999) found that the sorption complex in soils covered with stagnant flood water for a long time was enriched primarily with Ca^{2+} cations and, to a lesser extent, with Na^{+}, Mg^{2+} and K^{+}, which lead to a slight increase in their sorption capacity and saturation of the sorption complex with alkaline cations. The properties of soils analysed by these authors after the flood showed no significant changes compared with these parameters before the flood. In another study, CHODAK et al. (1999) found a high content

Table 3

Some soil properties (0-20 cm) in relation to the agronomic category

Agronomic category	pH_{KCl}	N_{min}	d.m.	$S\text{-}SO_4$	Salinity
		(mg kg^{-1})	(%)	(mg kg^{-1})	(mg NaCl dm^{-3})
Light	7.02ns*	20.6ns	88.8ns	1.67ns	0.24ns
Medium	6.29ns	32.1ns	89.6ns	1.72ns	0.27ns
Heavy	6.42ns	31.8ns	87.6ns	2.18ns	0.28ns

* – not significant

Table 4

Some soil properties (0-20 cm) in relation to soil pH

Soil pH	N_{min}	d.m.	$S\text{-}SO_4$	Salinity
	(mg N kg^{-1})	(%)	(mg kg^{-1})	(mg NaCl dm^{-3})
Acidic	41.2ns**	92.3*a**	1.22*a*	0.28ns
Slightly acidic	28.8ns	89.5*a*	1.80*ab*	0.30ns
Neutral	34.6ns	85.9*b*	2.39*b*	0.28ns
Alkaline	18.0ns	90.7*a*	1.68*ab*	0.25ns

* – homogeneous groups, ** – not significant

of macroelements and trace elements, particularly Zn and Cr, in alluvia transported by floodwaters. They also determined a neutral or alkaline pH in allotment garden soils. An experiment carried out by Lipiński and Bednarek (1999) in areas flooded in 1997 showed a considerable proportion of soils with a medium, high and very high levels of soluble forms of P, K and Mg, which were distinctly different from the mean values in the same regions. Similarly, Fageria et al. (2011) reported an increased content and availability of P and Mg accompanied by a decrease in the concentration and availability of S, Zn, and Cu in lowland rice soils. In another study conducted by Bednarek et al. (2011) after the 2010 flood in the middle Vistula River valley, it was found that the pH_{KCl} and the content of available phosphorus, potassium and magnesium in the layer 0-20 cm of arable land and grassland did not basically differ from the values reported before the flood. The soil agronomic category was significantly positively correlated with pH (r_{xy} = 0.465) and the available magnesium content (r_{xy} = 0.564), and negatively correlated with available phosphorus (r_{xy} = -0.730) and the K:Mg ratio (r_{xy} = -0.342). the soil pH was significantly positively correlated with the content of available phosphorus (r_{xy} = 0.315), available potassium (0.195), available magnesium (0.120) and the K:Mg ratio (r_{xy} = 0.140).

The other soil properties were assessed after the additional chemical analyses of 48 samples had been performed. No significant differences in the dry mass, mineral nitrogen, sulphate sulphur content and salinity were found between light, medium and heavy soils (Table 3). No major differences in the soil properties were found in relation to the pH, either (Table 4). In the flooded soils, the mineral N (N_{min}) content was significantly lowered, which was most probably associated with the denitrification process that occurred in the prevalent anaerobic conditions during the flood (Eulenstein et al. 1998). The total N content in flooded areas fluctuated, decreasing in most soils (Šerá et al. 2008). In turn, the high content of heavy metals indicates intensive sulphate oxidation and may be the cause rather than the result of a specific pH (Nagel et al. 2003).

The mean content of copper in the soil sampled in 14 villages was 22.8 mg Cu kg^{-1} d.m., being the lowest in Kępa Solecka (12.4) and the highest in Zastów Polanowski (52.9 mg Cu kg^{-1}). The mean content of zinc in the soils of the studied regions was 69.3 mg Zn kg^{-1}, being the lowest in the soils of Kępa Solecka (47.9 mg), and the highest in Zastów Karczmiska and Niedźwiada Duża (97.4 mg Zn kg^{-1}). A 10 sites, the content of cadmium was 0.27 mg Cd kg^{-1}; the highest level was found in the soil from Braciejowice (0.32 mg Cd kg^{-1}), and the mean content was 0.28 mg Cd kg^{-1}. The mean content of lead in the sampled soils was 12.1 mg Pb kg^{-1}; again, the lowest in Kępa Solecka (7.73 mg Pb kg^{-1}) but the highest in Zastów Karczmiska and Niedźwiada Duża (18.6 mg Pb kg^{-1}). The mean content of chromium was 24.7 mg Cr kg^{-1}, with the lowest level found in Kępa Solecka (13.4), and the highest one in Zastów Karczmiska (55.8 mg Cr kg^{-1}). The mean content of nickel in the analyzed soils was 24.9 mg Ni kg^{-1}, with the lowest result in Kępa Solecka (17.5), and the highest one in Zastów Karczmiska (35.4 mg Ni kg^{-1}). In turn, the mean content of arsenic in the soil samples was 4.09 mg As kg^{-1}, being the lowest levels in Dobre (2.64) and the highest in Zastów Karczmiska and Niedźwiada Duża (7.26 mg As kg^{-1}). The mean content of mercury in the soil samples was 0.046 mg Hg kg^{-1}, with the lowest one in Kępa Solecka (0.026) and the highest – in Niedźwiada Duża (0.069 mg Hg kg^{-1}).

Compared with the investigations carried out in this region by Lipiński and Bednarek (1999) after the 1997 flood, the present study has revealed an increased content of copper, zinc, chromium and nickel in the soil, while the levels of cadmium and lead were similar as before the flood. Notably, even if the levels of Cu, Zn and Ni were higher, they did not exceed the upper limits of natural amounts of these elements in soils (Kabata-Pendias et al. 1993, *Regulation* ... 2002). Similarly, Chodak and Perlak (1999) found elevated levels of zinc, copper and lead in the alluvial sediments after the 1997 flood. In turn, Gąsior et al. (2003) claimed that a flood did not induce a rise in the basic forms of Co, Ni and Cd, irrespective of the soil management practices. Long-term flooding resulted in the elevation of copper, zinc, chromium and manganese levels, although not to the extent that would be detrimental to crop plants. In another study carried out in the village Czernin (Mielec Community), Gąsior and Paśko (2007) found increased levels of soluble forms of some heavy metals (Cu, Zn, Pb, Cd Ni) following a 30-day long flooding. Simultaneously, they reported that such amounts in flooded soils did not pose a threat to agricultural production. In turn, a comparative study conducted in the Wrocław region before the 1997 flood afterwards, in

Table 5

Content of trace elements in soil (0-20 cm) in relation to the agronomic category

Agronomic category	Cu	Zn	Cd	Pb	Cr	Ni	As	Hg
	(mg kg^{-1})							
Light	11.8*a**	48.6*ab*	0.27ns**	7.36*a*	10.5*a*	13.5*a*	2.28ns	0.023*a*
Medium	18.3*a*	59.9*a*	0.29ns	10.9*a*	21.6*a*	22.0*b*	4.10ns	0.040*a*
Heavy	27.4*b*	78.9*b*	0.28ns	13.5*b*	28.4*b*	28.3*c*	4.21ns	0.054*b*

* – homogeneous groups, ** – not significant

1998, showed that the content of available Mn, Zn, Cu and Fe in the topsoil was considerably changed depending on the soil agronomic category (KUCHARZEWSKI, NOWAK 2000). The content of the two former elements decreased by an average 24%, and the two latter one declined by 13%. There was a general dependence between a higher soil firmness and smaller differences between the content of microelements before and after a flood. However, the content of the analysed microelements was in the typical range of concentrations for arable soils.

The content of cadmium and arsenic in the soil did not depend significantly on the agronomic category, whereas the levels of copper, lead, chromium, nickel and mercury were significantly higher in heavy than in medium and light soils (Table 5). Furthermore, the content of copper, zinc, nickel and arsenic was not significantly correlated with the soil pH, whereas the level of cadmium was significantly higher in alkaline than in the other types of soils. In flooded areas on the German side of the Odra River, the content of 3 elements, i.e. Cd, Cu, and Zn, exceeded the accepted German standards (EULENSTEIN et al. 1998). Additionally, the study revealed an increase in the Sr and Al content accompanied by a decrease in the Mn level in the post-flood areas, compared with regularly flooded land. In an area situated 146 m from the Rhein River, which is flooded on average for 47 days per year, at the mean soil pH 7.8, the biggest differences in the results were obtained for Cd (6.4-fold), Pb (5.1-fold), and Cu (5-fold), while the smallest differences were found for Ni (2.7-fold) and Hg (3-fold) (SCHIPPER et al. 2011). Moreover, a comparison of results from the three studied areas demonstrated that two factors, i.e. distance from the river (146 m versus 262 or 269 m), as well as flooding period (47 days per year as compared with 12), elevated the mean content of all the metals tested, i.e. As, Cd, Cr, Cu, Hg, Pb and Zn, with the exception of Ni (SCHIPPER et al. 2011). Areas in the middle part of the Elbe River that were flooded for a longer time and exposed to more intensive floods exhibited a statistically higher concentration of heavy metals such as Cd, Cu, Hg, Pb and Zn, compared with areas that were less frequently and less intensively flooded (ZIMMER et al. 2011). Furthermore, the concentration of Cd, Cu, Hg, and Zn in the 0-10 cm layer was significantly higher than in the 10-20 cm layer. Presence of lead, chromium and mercury in soils in relation to the soil pH varied most considerably

Table 6

Content of trace elements in soil (0-20 cm) in relation to the soil pH

Soil pH	Cu	Zn	Cd	Pb	Cr	Ni	As	Hg
	(mg kg^{-1})							
Acidic	20.1ns**	68.6ns	0.28a*	12.8ab	30.0a	23.5ns	4.92ns	0.051ab
Slightly acidic	23.1ns	78.1ns	0.27a	13.0b	28.0a	26.9ns	4.40ns	0.052b
Neutral	23.2ns	63.0ns	0.27a	10.8a	20.8b	23.6ns	3.76ns	0.041a
Alkaline	23.1ns	67.5ns	0.35b	13.2ab	23.6ab	25.5ns	3.48ns	0.047ab

* – homogeneous groups, ** – not significant

Table 7

Correlation between the trace element content and some soil properties (correlation coefficients, $n = 48$, $p \leq 0.05$)

Variable	Cu	Zn	Cd	Pb	Cr	Ni	As	Hg
Agronomic category	0.542	0.426	*	0.505	0.451	0.611	*	0.530
pH_{KCl}	*	*	0.309	*	–0.375	*	–0.356	*
$P_{available}$	0.485	*	*	0.303	*	*	0.295	0.292
$K_{available}$	0.418	*	*	*	*	*	*	*
$Mg_{available}$	0.494	0.367	*	0.367	*	0.594	*	0.299
N_{min}	0.487	*	*	0.294	*	0.326	0.293	0.345
d.m.	*	*	*	*	*	*	*	*
$S\text{-}SO_4$	*	*	*	*	*	*	*	*
Salinity	0.434	*	*	*	*	0.306	0.288	0.359

* – non-significant correlation

(Table 6). The biggest differences were found in the mean content of Cd, Cr and Cu between the 3 studied locations, ranging between 2.3- and 3.2-fold values (SCHIPPER et al. 2011).

Comparative analyses of the heavy metal content in post-flood areas on the Polish and German sides of the Odra River demonstrated comparable values within an acceptable range, posing no risk to agricultural production, with the exception of Cd, Cu and Zn (EULENSTEIN et al. 1998). In turn, the investigations carried out by ŠERÁ et al. (2008) showed elevated levels of all analysed heavy metals, i.e. Zn, Pb, Cr, Ni and Cd, with the exception of Hg, in most soil samples. The highest rise in the heavy metal content was reported from the riparian areas in Morava, which was probably caused by contamination imported from the upper part of the river basin. According to the cited authors, an increased content of heavy metals may threaten riparian ecosystems, especially when flood-induced metal mobility in soil profiles in stimulated.

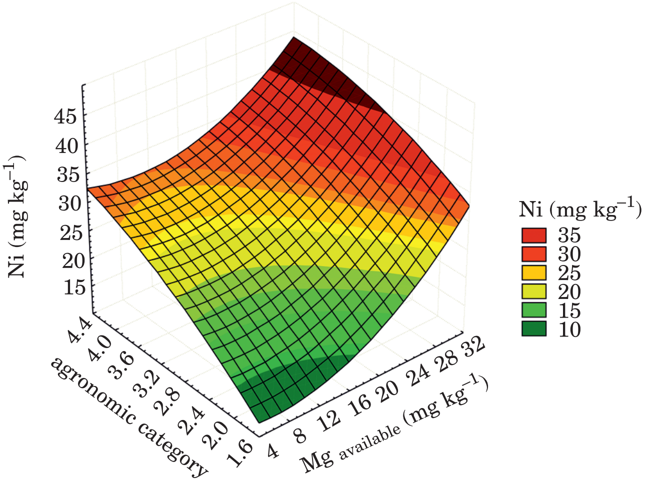

Fig. 2. Correlation between the content of Ni in soil, the agronomic category and available Mg content in soil

In the current research, it was found that the content of copper and mercury in the tested soils were most strongly correlated with the examined properties (agronomic category, pH, the content of available phosphorus, potassium and magnesium, the content of mineral nitrogen, dry mass, sulphate sulphur and salinity). The content of cadmium was the least dependent on these properties. An effect of the agronomic category and the content of available Mg on the Ni content in soil was demonstrated (Table 7, Figs 1, 2). Similarly, in their study of the eastern side of the middle Vistula River valley, GĄSIOR and PAŚKO (2007) found that the content of soluble forms of elements in flooded soils was correlated with the proportion of particles with diameter <0.02 mm, pH (Ca, Mg, Fe, Mn, Cu, Pb, Cd, Co and Ni), and humus content (Fe, Pb and Cd).

CONCLUSIONS

After the flood which struck the middle Vistula River valley in 2010, the pH of soils form horticultural plantations was acidic, slightly acidic and neutral, while the content of available phosphorus was primarily moderate. The content of this element was moderate in very light and heavy soils and high in light and medium soils.

The content of available potassium in the soils ranged from 125.5 to 183.6 mg K kg^{-1}. The potassium content was high in very light, light and medium soils, and moderate in heavy soils. The K:Mg ratio was most often close to 1.

The content of available magnesium in orchard soils ranged from 78.8 to 216.3 mg Mg kg^{-1}. The content of this element was high in very light soils, and very high in light, medium and heavy soils.

Compared with soils before the flood, the values of pH$_{KCl}$ and the available phosphorus content were not elevated, unlike the levels of available potassium and magnesium, which had risen.

The content of dry mass, N$_{min}$, S-SO$_4$ and salinity was not significantly correlated with the soil agronomical category and pH. The content of trace elements (Cu, Zn, Cd, Pb, Cr, Ni, As, Hg) in the soil remained on a level equal the geochemical background but was slightly higher than before the flood.

The investigations indicated no considerable deterioration of the physicochemical soil properties after the 2010 flood, which could affect negatively yield volumes and quality of cultivated plants, including fruit trees and shrubs.

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