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CHANGES OF CHEMICAL PROPERTIES OF BRUNIC ARENOSOLS (RUSTY SOILS) AFTER ELEVEN YEARS OF THEIR FALLOWING

ZMIANY WŁAŚCIWOŚCI CHEMICZNYCH GLEB RDZAWYCH TYPOWYCH (BRUNIC ARENOSOLS) PO JEDENASTU LATACH ODŁOGOWANIA

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Streszczenie. Porównano właściwości chemiczne (pH, właściwości sorpcyjne, zawartość próchnicy, Al^{+3}, H^{+}, przyswajalne dla roślin Mg, P, K) gleb rdzawych typowych (Brunic Arenosols) przed odłogowaniem i po upływie 11 lat od zaprzestania uprawy. Właściwości zostały oznaczone według metod powszechnie obowiązujących w gleboznawstwie. Odnotowano, że gleby odłogowane zawierały istotnie większą ilość próchnicy niż gleby uprawne. Odłogowanie sprzyjało zakwaszeniu gleb, które następowało z różną intensywnością w profilu glebowym, w zależności od uziarnienia. Proces zakwaszania związany był ze zmniejszeniem się sumy zasadowych kationów wymiennych (S), kationowej pojemności wymiennej (T) i stopnia wysycenia kompleksu sorpcyjnego zasadami (V) oraz ze zwiększeniem zawartości wymiennych form glinu i wodoru. Gleby odłogowane zawierały więcej przyswajalnego magnezu i fosforu niż gleby uprawne, natomiast ilość potasu przyswajalnego była porównywalna.

Key words: available macroelements, Brunic Arenosols (typical rusty soils), fallows, pH, sorption properties.
Słowa kluczowe: Brunic Arenosols (gleby rdzawe typowe), pH, przyswajalne makroelementy, właściwości sorpcyjne, odłogi.

INTRODUCTION

Soil fallowing in Poland has gained momentum in the early 90s as a result of economic changes which then have occurred. Intensification of this process took place in Western Pomerania, where dominated state-owned farms (PGR), where first were fallowed the soils exposed to erosion, located in moraine areas and sandy soils with low productivity, particularly vulnerable to acidification.

The changes in soils chemistry as a result of their exclusion from agricultural production are primarily dependent on fallowing period, climatic conditions, type of soil and landform. According to Baran et al. (2001), Łętkowska and Strączyńska (2001), short-term fallowing does not change pH and soil abundance in macroelements. Wójcikowska-Kapusta et al. (2003) confirmed that fallowing period from three to eight years had not a significant impact on total phosphorus and potassium content and content of their bioavailable forms in soils. Łętkowska and Strączyńska (2001) emphasized that significant chemistry changes, including

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soil pH, take place only after a long period of fallowing (9–10 years). The researchers agree that fallowing reduces the risk of soil erosion (Van Rompaey et al. 2001), and in conditions of intense succession of vegetation, weakens this process. In respect of other fallowing effects, opinions of scientists are divided. Some of them believe that fallowing leads to improvement of water-air properties of soil (Słowińska-Jurkiewicz et al. 1999), of growth of organic compounds content and enriches soil in mineral ingredients. This is accompanied by increase of biological activity and improvement of trophic properties (Malicki and Podstawka-Chmielewska 1998; Martyn et al. 1998; Maly et al. 2000; Podstawka-Chmielewska and Kurus 2007), increase of pH values and base saturation (Chudecka and Tomaszewicz 2004), and reducing of leaching from soil nitrogen and phosphorus which are responsible for eutrophication (Czarnecki et al. 1994; Webster and Goulding 1995; Rekolainen et al. 1999).

According to other researchers, the fallowing causes soil degradation, manifested among others by impoverishment of soil complex in base cations (Sienkiewicz et al. 2003; Strączyńska and Strączyński 2003; Licznar et al. 2009a) and decrease of organic carbon content (Wojnowska et al. 2003; Żukowska et al. 2007).

The aim of the study was to determine changes in chemistry of Brunic Arenosols (typical rusty soils), which occurred as a result of their eleven-years of fallowing. For this purpose authors compared the chemical properties of cultivated soils (soil profiles with all genetic horizons) and the same soils but after 11 years after of their fallowing.

MATERIAL AND METHODS

The authors investigated properties of soils identified as Brunic Arenosols (typical rusty soils) (PTG 2011), which are located within the glacial plain in the vicinity of Ginawa village (region zachodniopomorskie). These soils made of sands are predominant on this area, they are classified according to soil-agricultural map to the sixth complex agricultural suitability (6Bw pgl·ps:pl and 6Bw pgl·pl). In 1988 on arable field the four soil profiles were made, spaced from each other 10–15 m. Soil cultivation on this field was abandoned in 1990, and in 2001, ie. after eleven years of this fallowing, again the four soil profiles were made near previous location. In 2001, the researched field was covered by young pine trees and between them appeared herbaceous plants. In both cases the soil materials for laboratory analysis was taken from four separated genetic horizons of soil profiles.

In soil samples were determined the following properties:

- grain composition by aerometric method of Casagrande in Prószyński modification; division of soil materials on granulometric fractions and groups was made according PTG (2011);
- pH by potentiometric method in KCl with concentration of 1 mol · dm^{-3} (pH_{KCl}); mean pH values correspond to arithmetic mean values of hydrogen ions concentration;
- organic carbon content by Tiurin method; on base which humus content was calculated using the formula Corg. · 1,724;
- base capacity (BC) and hydrolytic acidity (HA) by Kappen method; on basis of which were calculated cations exchange capacity (CEC = BC + HA) and base saturation (BS = BC/CEC · 100%);

- content of exchangeable forms of Al^{+3} and H^+ by Sokołow method;
- content of available forms of: magnesium by Schachtschabel method, potassium and phosphorus by Egner-Riehm method.

In Table 1 are shown data of soil grain composition in form of mean values for each of genetic horizons from eight soil profiles, assuming that this property has not changed after 11 years.

In Tables 2, 3 are shown values of soil chemical properties in form of mean values calculated for following genetic horizons from the four soil profiles of arable soils (made in 1988) and for the four soil profiles of fallowed soils (made in 2001). The assessment of soil richness in available phosphorus, potassium and magnesium was made based on the recommendations of IUNG (Obojski and Strączyński 1995).

The significance of differences of researched soil properties was calculated by using t-Student test, using partial values (not averaged), using statistical functions of Microsoft Excel 2002 (Table 4).

RESULTS AND DISCUSSION

Brunic Arenosols (typical rusty soils) from Ginawa are formed with sandy materials with large domination of sand fraction, which content increases with profile depth, unlike than content of silt and clay (Table 1). The upper layers of soils are built from materials with grain composition of sandy loam and loamy sand, but the lower parts of soils are built from sands (acc. PTG 2011).

Table 1. Grain composition of soils (mean values)
Tabela 1. Skład granulometryczny gleb (wartości średnie)

Symbol and depth of genetic horizons Symbol i głębokość poziomów genetycznych [cm]	Percentage content of fraction with diameter Procentowa zawartość frakcji o średnicy [mm]			Granulometric group Grupa granulometryczna
	2.0–0.05	0.05–0.002	<0.002	
A 0–30 cm	74.4	19.5	6.1	sandy loam – glina piaszczysta
Bv1 30–50 cm	80.6	15.3	4.1	loamy sand – piasek gliniasty
Bv2 50–90 cm	92.1	5.3	2.6	sand – piasek słabogliniasty
C 90–150 cm	94.0	4.1	1.9	sand – piasek luźny

After eleven-years of fallowing, the investigated soils were enriched in humus, which content (according mean values) increased by more than 50% in A horizon, more than double in Bv1 horizon and nearly three times in Bv2 horizon (Table 2). The significance of changes in humus content has been statistically confirmed only for A horizon (Table 4). The observed differences are caused by different species composition of vegetation on soils used differently. In conditions of plant cultivation their above-ground parts are emptied from field almost entirely in the aim of obtaining of yields. A small amount of crop residues which remain on field usually does not balance of organic matter losses by annual mineralization and thus does not increase content of humus in soil. On the fallowed soils in time appears more and more dense overgrowth of perennial vegetation, which roots penetrate deeper layers of soil, enriching them in organic matter.

Table 2. Basic chemical properties of soils (mean values)
Tabela 2. Podstawowe właściwości chemiczne gleb (wartości średnie)

Symbol and depth of genetic horizons Symbol i głębokość poziomów genetycznych [cm]	Humus content Zawartość próchnicy [g · kg^{-1}]	pH w – in 1M KCl	Sorption properties Właściwości sorpcyjne			
			base capacity (BC)	hydrolytic acidity (HA)	cations exchange capacity (CEC)	base saturation (BS)
			cmol · kg^{-1}			%
	field / fallow pole / odłóg	field / fallow pole / odłóg	field / fallow pole / odłóg	field / fallow pole / odłóg	field / fallow pole / odłóg	field / fallow pole / odłóg
A 0–30 cm	15.5/24.5	4.0/4.1	0.7/3.1	5.4/6.6	6.1/9.7	9.7/31.5
Bv1 30–50 cm	2.8/5.8	4.3/4.1	0.6/1.3	3.7/2.6	4.3/3.9	14.3/32.0
Bv2 50–90 cm	0.5/1.4	4.4/3.9	1.2/0.8	2.0/1.6	3.2/2.4	33.5/28.2
C 90–150 cm	–	5.1/4.7	2.7/1.6	1.2/1.3	3.9/2.9	66.3/51.8

Explanations – Objaśnienia: base capacity (BC) – suma zasadowych kationów wymiennych (S), hydrolytic acidity (HA) – kwasowość hydrolityczna (Hh), cations exchange capacity (CEC) – kationowa pojemność wymienna (T), base saturation (BS) – stopień wysycenia kompleksu sorpcyjnego zasadami (V).

A higher humus content in soils excluded from agricultural production is the most emphasized effect of fallowing that resulting from intensive turf growth, which was confirmed, among others, by Martyn et al. (1998), Maly et al. (2000), Łętkowska (2001), Niemyska--Łukaszuk et al. (2002), Chudecka and Tomaszewicz (2004), Podstawka-Chmielewska and Kurus (2007). A significant increase of humus content in sandy soils after 12-year period of their fallowing also was noted by Licznar et al. (2009, 2009a). A decrease of humus content in fallowed soils is a situation rarely noted, confirmed among others by Strączyńska and Zawieja (2001) and Żukowska et al. (2007).

With respect to the changes that have occurred in pH and sorption properties, it clearly became the division of soil profile into two parts: the top part to 50 cm and the deeper part 50–150 cm, in which changes present themselves differently (Table 2, 3). In the upper part of soil profile (horizons A, Bv1) the mean values of pH in two periods of study were similar (Table 2). The deeper part of soil (50–150 cm) had visibly acidification because in that case there has been the decrease of mean pH value of 0.4–0.5. Besides a stronger acidification the fallowed soils had clearly decreased of base capacity (BC) and hydrolytic acidity (HA) and thereby decreased of cation exchange capacity (CEC) and base saturation (BS) (Table 2). In A horizon, which noted increase of mean pH of 0.1, changes of sorption properties had a different direction, ie. values of BC, HA, CEC and BS were increased, which in relation to BC, CEC and BS was confirmed as statistically significant changes and highly significant changes (Table 4). It should be noted that the analyzed soils were significantly acidified during agricultural use, and between of their genetic horizons the lowest pH value had A horizon (Table 2). The difference of mean pH values found when between soil horizons was 1.1 and after 11 years of fallowing it decreased to 0.8 due to stronger acidification of lower parts of soil profile. It seems that in period of fallowing on degree of stronger acidification of soil horizons had influenced their grain composition. A top soil horizons characterized by a more concise grain composition (sandy loam and loamy sand) compared to deeper soil horizons Bv2 and C (sand) (Table 1). In addition, soils in A horizon have been enriched with organic matter that resulted a higher resistance to acidification.

Table 3. Content of exchangeable forms of H, Al and available forms of Mg, P, K (mean values)
Tabela 3. Zawartość wymiennych form H i Al oraz przyswajalnych form Mg, P, K (wartości średnie)

Symbol and depth of genetic horizons Symbol i głębokość poziomów genetycznych [cm]	Content of exchangeable forms of Zawartość form wymiennych		Content of available forms and assessment of their contents acc. Obojski and Strączyński (1995) Zawartość form przyswajalnych makroskładników oraz ocena zasobności wg Obojskiego i Strączyńskiego (1995)		
	H^+	Al^{3+}	Mg	P	K
	cmol · kg^{-1}		mg · kg^{-1}		
	field / fallow pole / odłóg	field / fallow pole / odłóg	field / fallow pole / odłóg	field / fallow pole / odłóg	field / fallow pole / odłóg
A 0–30 cm	0.14/0.24	1.11/0.92	16.3/23.2 very low / low bardzo niska / niska	19.5/77.4 very low / high bardzo niska / wysoka	54.2/58.2 low / low niska / niska
Bv1 30–50 cm	0.09/0.23	0.62/0.50	8.0/22.0 very low / low bardzo niska / niska	6.5/20.7 very low / very low bardzo niska / bardzo niska	38.9/38.2 very low / very low bardzo niska / bardzo niska
Bv2 50–90 cm	0.07/0.24	0.30/0.47	13.1/29.9 low / medium niska / średnia	6.1/23.5 very low/very low b.niska/b.niska	50.5/46.0 low / low niska / niska
C 90–150 cm	0.04/0.22	0.06/0.14	19.3/28.4 low / medium niska / średnia	9.0/25.8 very low / very low bardzo niska / bardzo niska	42.0/43.4 low / low niska / niska

An acidification, next to the increase of organic carbon content, is very frequently noted effect of fallowing soils. Łętkowska and Strączyńska (2001) concluded that significant changes in soil pH should be expected after 9–0 years of fallowing, though Łętkowska (2001) reported significant acidification of soil humus horizon after several years of fallowing. An increase of acidification of fallows together with a decrease of exchangeable base cations emphasize also Strączyńska and Zawieja (2001), Niemyska-Łukaszuk et al. (2002), Strączyńska and Strączyński (2003), Wojnowska et al. (2003), Koćmit et al. (2008), Licznar et al. (2009, 2009a).

A stronger acidification of Bv2 and C horizons (50–150 cm) caused of appearance in them of greater amounts of exchangeable aluminum (Al^{3+}) while in A and Bv1 horizons (0–50 cm) content of this toxic to plants component was reduced (Table 3). The highest increase of exchangeable aluminum content, more than doubled and statistically significant, was observed in C horizon (Table 4).

Table 4. Significance of differences between properties of cultivated and fallow soils found using Student's test
Tabela 4. Istotność różnic pomiędzy właściwościami gleb uprawnych i odłogowanych, stwierdzona przy użyciu testu t-Studenta

Variable Zmienna / Genetic horizon Poziom genetyczny	Available forms of Przyswajalne formy		Humus	BC S	CEC T	BS V	H^+	Al^{3+}	EA Hw
	Mg	P							
A	ns.	ns.	0.018*	0.001**	0.012*	0.000**	0.004**	ns.	ns.
Bv1	0.004**	0.002**	ns.	ns.	ns.	ns.	0.000**	ns.	ns.
Bv2	ns.	0.001**	ns.	ns.	ns.	ns.	0.002**	ns.	ns.
C	0.040*	0.009**	ns.	ns.	ns.	ns.	0.000**	0.031*	0.000**

Explanations – Objaśnienia: ns. – no significant dependence – zależność nieistotna, * significant dependence – zależność istotna (α = 0,05), ** highly significant dependence – zależność wysokoistotna (α = 0,01), BC – base capa city – suma zasadowych kationów wymiennych (S), CEC – cations exchange capacity – kationowa pojemność wymienna (T), BS – base saturation – stopień wysycenia kompleksu sorpcyjnego zasadami (V), EA – exchangeable acidity – kwasowość wymienna (Hw).

According Filipek and Dechnik (1995), content of exchangeable aluminum at the level similar and higher than 0.5 cmol · kg^{-1} is the amount toxic for plants. In this aspect the soil material from layer 0–50 cm created unfavorable conditions for growth and development of crops. The increase of content of exchangeable Al^{3+} as consequence of soil acidification was confirmed among others by Filipek et al. (2000), Koćmit et al. (2008), Tomaszewicz and Chudecka (2010).

An acidification of soils fallowed by 11 years was confirmed by significant increase of H^+ cations content in sorption complex of each genetic horizon (Table 3, 4). This indicates that all soil horizons are subjected to acid degradation processes. Licznar et al. (2009) also noted a significant increase of hydrogen ions content strongly associated with complex sorption of soils as a result of 12-years period of their fallowing.

After 11-years period of fallowing the genetic horizons Bv1, Bv2, C contained significantly higher amounts of available phosphorus than during of agricultural use (Table 3, 4). The content of available magnesium increased highly significantly in horizon Bv1 and significantly in horizon C. The content of this macroelement increased so much that there was a change of soil fertility from category “very low” to “low” or from category “low” to “medium”. The content of available phosphorus also increased in each of genetic horizon but particularly pronounced in humus horizon (A), where fertility of soil material in this macroelement changed from category “very low” to “high”, probably caused by increase of humus content. The available potassium content was comparable in both periods of research.

The opinions of researchers about the content of available macroelements in fallowed soils are very different. Zawieja (2007) noted an increase of available potassium content as a result of fallowing but Niedzwiecki et al. (1998) noted a decrease of available form of this macroelement in A horizon as a result of short-term period of leaving of soils without agrotechnical treatments. Łętkowska and Strączyńska (2001) noted also that soils fallowed by 9–10 years contained less available potassium than arable soils. Strączyńska et al. (2010) noted that abandonment of cultivate silty and loamy soils caused a decrease of available phosphorus and potassium content, resulting by lack of soil fertilization and by leaching of elements in conditions of very acidic pH. However, in fallowed sandy soil the content of phosphorus and potassium was higher than in cultivated soil with the same grain composition, as the authors explained by a lesser downloading of these elements by plants growing on fallow. Wójcikowska-Kapusta et al. (2003) found no significant difference in content of available potassium and phosphorus in sandy soils: used for agricultural purposes and fallowed by 3–8 years. Tomaszewicz and Chudecka (2010) emphasized that soils fallowed by 8–10 years contained more of available magnesium and phosphorus but less available potassium compared to period when they were used for agricultural purposes. Włodek et al. (2014) also noted a higher content of available phosphorus, potassium and magnesium in soil fallowed by 7 years, which the authors explained by lack of removal of those elements with yields of crop.

CONCLUSIONS

1. Brunic Arenosols (typical rusty soils) fallowed by 11-years were enriched in humus in the layer 0–90 cm, but statistically significant increase of this component content was confirmed only in A horizon.

2. A fallowing period caused acidification of soils but this process occurred with different intensity, depending on grain composition of soil materials. The strongest acidification took place in Bv2 and C horizons, built of sands. In Bv1 horizon, built of loamy sand, an acidification was lower, and in humus horizon – A, built of sandy loam, there was no decrease pH as a result of set-aside.
3. After eleven-years of fallowing all the soil genetic horizons had a higher content of available magnesium and phosphorus than in period of their agricultural use, while the content of available potassium was comparable.

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Abstract. The aim of study was to compare of chemical properties (pH, sorption properties, content of humus, Al^{+3}, H^{+}, available forms of Mg, P, K) of Brunic Arenosols (typical rusty soils) from time of their agricultural use and after 11 years of their fallowing. Properties were determined by methods commonly applicable in soil science. It was found that fallowed soils contained significantly higher amount of humus than those cultivated. Fallowing period favored the acidification of soils, but this process occurred with different intensity in soil profile, depending on grain composition. Acidification process was associated with decrease of base capacity (BC), cation exchange capacity (CEC) and base saturation (BS) and increase of content of exchangeable aluminum and hydrogen forms. Fallowed soils contained a higher content of available magnesium and phosphorus than arable soils, while amount of available potassium was comparable.