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SELECTED PHYSICAL AND CHEMICAL PROPERTIES AND THE STRUCTURE CONDITION OF PHAEOZEMS FORMED FROM DIFFERENT PARENT MATERIALS
Part I. Physical and chemical properties

Summary

The performed investigations aimed at determining physical and chemical properties of proper Phaeozems, especially their diversification in soils developed from different geological formations. The following parameters were determined in the examined soils: texture of soil, bulk density, specific density, porosity, moisture content, hygroscopic water capacity (H) and maximum hygroscopicity (MH), liquid and plastic limits, content of available elements, organic carbon and total nitrogen, hydrolytic acidity, reaction and others. The authors determined, among others: high natural moisture content and density (especially in soils developed from clays), strongly diversified H and MH values correlated with the content of the clay fraction and moisture contents at the limits of liquidity and plasticity. All the analysed soils were characterised by the reaction close to neutral, optimal C:N ratio as well as strong sorption capabilities. They were potentially abundant in nutrient resources and did not exhibit salinity.

WYBRANE WŁAŚCIWOŚCI FIZYCZNE I CHEMICZNE ORAZ STAN STRUKTURY CZARNYCH ZIEM WYTWORZONYCH Z RÓŻNYCH SKAŁ MACIERZYSTYCH
Część I. Właściwości fizyczne i chemiczne

Streszczenie

Przeprowadzone badania miały na celu poznanie właściwości fizycznych i chemicznych czarnych ziem właściwych, a w szczególności ich zróżnicowania w glebach wytworzonych z odmiennych utworów geologicznych. W badanych glebach oznaczono m.in.: uziarnienie, gęstość objętościową oraz gęstość fazy stałej, porowatość, wilgotność, H i MH, granice: płynności i plastyczności, zawartość składników przyswajalnych ,węgla organicznego i azotu ogólnego, kwasowość hydrolityczną, odczyn i inne. Stwierdzono, między innymi: wysoką wilgotność naturalną i gęstość (szczególnie w glebach wytworzonych z iłów), silnie zróżnicowane, skorelowane z zawartością iłu koloidalnego, wartości H, MH oraz wilgotności przy granicach: płynności i plastyczności. Wszystkie analizowane gleby chąrakteryzowały się odczynem zbliżonym do obojętnego, optymalnym stosunkiem C:N oraz silnymi zdolnościami sorpcyjnymi. Gleby te były potencjalnie zasobne w składniki pokarmowe. Nie wykazywały zasolenia.

Introduction

The importance of the Phaeozems types of soils for agriculture cannot be overestimated, even though they take up barely 1.5% of the total area of arable land [19]. They are classified among the best arable lands and grasslands (with the exception of Phaeozems underlaid with sand). Phaeozems which are found most frequently in the form of not very large patches neighbouring with other mineral formations often co-create the so called "soil mosaic" which are usually (wrongly) utilised in the same way. Locally, they can form extensive complexes of Phaeozems, e.g.: Kujawy [4, 5, 14], Kętrzyn [24], Gniezno [12], Wrocław [2, 9]. Pyrzyce [3, 6], Kalisz [11], Kutno [8], Szamotuły [20], Gniew [16, 23] and other soils. The shallow location of the ground water table in these soils is frequently associated with significant problems in their cultivation. This problem is particularly annoying in Phaeozems with a significant proportion of the clay fraction in the arable-humus horizons. For the same reasons, black earths are extremely sensitive to the degradation caused by unfavourable changes in water-air relationships [17]. These soils exhibit a distinctly polygenetic character which leads to considerable diversification of both their morphology and properties [21].

The objective of this research project was to recognize physical and chemical properties of Phaeozems, in particular, their variability in the soils developed from different geological formations.

Materials and methods

Field experiments were carried out on the area of one of the largest complexes of Phaeozems in Poland. Investigations were conducted on soils selected in such a way as to represent their variability with regard to parameters determining their agricultural usefulness and, at the same time, developed from a different parent materials. They included: two Kujawy Phaeozems from the region near Inowrocław developed from boulder clays of the Baltic glaciations - Würm (profiles 1 and 2), Środa Phaeozems from the neighbourhood of Rogalin formed from loamy sands and sandy clays also from the Baltic glaciations - Würm (profile 6), soil from the region of Wrocław developed from fluvioglacial materials of the central Polish glaciations – Riss (profile 5), two Gniew Phaeozems formed from clays of the Würm pressure moraine (profiles 3 and 4). After the description of their morphological structure, deformed and intact soil samples (V = 100 cm^3) were collected from the individual genetic horizons of the examined soils. The following properties were determined in them: texture – by the areometric method [15], specific density – by the pycnometric method [18], natural and hygroscopic moisture content – gravimetrically, maximum hygroscopic capacity – in a negative pressure chamber in the presence of saturated K_2SO_4 solution, bulk density – using Nitzsch's vessels, porosity calculated on the basis of soil density assays and solid phase density, plastic limit (W_p) – using the rolling method, liquidity limit (W_l) – by the Casagrande method, reaction – using a potentiometer, Electrical Conductivity – using a conductivity meter (soil solution 1:1), $CaCO_3$ content – by the Scheilbler method, hydrolytic acidity (H_h) – using the Kappen method, Cation Exchange Capacity (CEC), Total Exchangeable Bases (TEB) – by the Metson method, the content of the available macronutrients – using Egner-Riehm and Schachtschabel methods, content of organic carbon – by the Tiurin method and the content of total nitrogen methods – by the Kiejdahl method [13]. The correlation coefficient (α=0.05) achieve with the use of Microsoft Exel. The presented results are mean values from five replications.

Results and discussion

Morphological properties were described and taxonomic classification presented in accordance with the recommendations of the Polish Soil Science Society (PTG) [22]. All the examined soils were classified as Phaeozems. Their texture was characteristic for the soils of the appropriate taxon occurring in Poland [1, 7] and it was mostly "heavy" since Phaeozems of lighter texture usually represent subtypes of degraded Phaeozems. The authors found considerable species variability – from silt, through clay to loam. The minimal content of the clay fraction clay in arable-humus horizons amounted to 10% (profile 6) and maximal – to 54% (profile 4). This value in the remaining soils fluctuated within wide range (14-51%). High content of silt in soil No. 5 (up to 52%) was significant (Tab. 1). Soil density as well as its porosity depended on the content of the colloidal fraction and the depth from which the given sample was collected. Bulk density values obtained in epi- and endopedons were assessed as high. In the case of A_p horizons, these values ranged from 1.26 to 1.60 $Mg \cdot m^{-3}$, at porosities, respectively 0.4583 and 0.3787 $m^3 \cdot m^{-3}$. On the other hand, in the case of horizons situated deeper, they were considerably higher, e.g. 1.79 $Mg \cdot m^{-3}$, at porosity - 0.3271 $m^3 \cdot m^{-3}$, (profile 1, depth: 0.7 – 0.8 m), or 1.89 $Mg \cdot m^{-3}$, at porosity - 0.2868 $m^3 \cdot m^{-3}$ (profile 6, depth 1,2 – 1.3 m) (Tab. 2). A relatively low and uniform bulk density to the depth of 1 m was observed only in profile 5 with the texture characterised by a significant proportion of the silt fraction (Tab. 2). The above-mentioned values were also influenced by the moment of sample collection (after intense precipitation) in which the density of the examined soils was close to field maximum. This was also reflected in the high values of the determined natural water content – in the top layers: from 0.1483 $kg \cdot kg^{-3}$ (profile 6) to 0.37 $kg \cdot kg^{-3}$ (profile 3). Moisture contents at the plasticity and liquidity limits determined for arable-humus horizons were significant, especially for very heavy soils (profiles 3 and 4). These parameters, being constant for a given soil, should be taken into consideration when designing the working parts of agricultural machines and calculating demands for power.

Table 1. Morphology and texture of investigated soils

Number of profile	Genetic horizon	Depth	Percentage content of fractions in diameter [mm]			Textural group acc.	Textural group acc.
		[m]	2-0.05	0.05-0.002	<0.002	PN	FAO
1	A_p	0.1-0.2	58	27	15	gl	SL
	A_1	0.3-0.35	56	27	17	gl	SL
	A_1C_{ca}	0.5-0.6	50	30	20	g	L
	C_{ca}	0.7-0.8	45	32	23	g	L
2	A_p	0.1-0.2	62	24	14	gl	SL
	A_1C	0.35-0.4	63	16	21	gs	SCL
	C_{ca}	0.8-0.9	52	27	21	g	SCL
3	A_p	0-0.2	21	28	51	i	C
	A_1C	0.35-0.4	17	24	59	i	C
	C_g	0.5-0.6	25	20	55	i	C
	C_{ca}	0.7-0.8	26	20	54	i	C
	C_{ca}	1.2-1.3	30	14	56	i	C
	IIC	1.4-1.5	46	16	38	ip	SC
4	A_p	0-0.35	26	20	54	i	C
	A_1C	0.5-0.6	14	18	58	i	C
	C_{cag}	1.1-1.2	16	18	66	ic	C
5	A_p	0.05-0.15	24	52	24	gpł	SiL
	A_1C	0.3-0.35	27	48	25	gpł	SiL
	C	0.45-0.55	26	52	22	gpł	SiL
	IIC	0.8-0.9	65	18	17	gl	SL
	IIIC	1.3-1.4	62	18	20	gl	SL
6	A_p	0.1-0.15	70	20	10	gp	SL
	A_1	0.25-0.35	73	13	14	gp	SL
	A_1C	0.4-0.5	76	10	14	gp	SL
	C_{ca}	0.5-0.6	67	20	13	gp	SL
	C_{1ca}	0.8-0.9	65	22	13	gp	SL
	C_{2gca}	1.2-1.3	72	14	14	gp	SL
	C_{3ca}	1.4-1.5	62	18	20	gp	SCL

Table 2. Basic physical properties of investigated soils

Number of profile	Genetic horizon	Depth	Moisture		Specific density	Bulk density	Porosity
		[m]	[kg·kg^{-3}]	[m^{3}m^3]	[Mg·m^{-3}]	[Mg·m^{-3}]	[m^{3}m^3]
1	A_p	0.1-0.2	0.1581	0.2523	2.57	1.60	0.3787
	A_1	0.3-0.35	0.0758	0.1168	2.56	1.54	0.3984
	A_1C_{ca}	0.5-0.6	0.0986	0.1716	2.65	1.74	0.3434
	C_{ca}	0.7-0.8	0.1143	0.2946	2.66	1.79	0.3271
2	A_p	0.1-0.2	0.1789	0.2766	2.53	1.55	0.3886
	A_1C	0.35-0.4	0.0720	0.1082	2.57	1.50	0.4150
	C_{ca}	0.8-0.9	0.0853	0.1203	2.62	1.41	0.4618
3	A_p	0-0.2	0.3710	0.4663	2.32	1.26	0.4583
	A_1C	0.35-0.4	0.1972	0.3175	2.51	1.61	0.3585
	C_g	0.5-0.6	0.1476	0.2568	2.68	1.74	0.3507
	C_{ca}	0.7-0.8	0.1299	0.2260	2.70	1.74	0.3555
	C_{ca}	1.2-1.3	0.1347	0.2357	2.72	1.75	0.3566
	IIC	1.4-1.5	0.1134	0.1939	2.66	1.71	0.3571
4	A_p	0-0.35	0.2436	0.3424	2.41	1.41	0.4170
	A_1C	0.5-0.6	0.2054	0.3348	2.41	1.63	0.3236
	C_{cag}	1.1-1.2	0.1486	0.2571	2.72	1.73	0.3640
5	A_p	0.05-0.15	0.1610	0.2220	2.43	1.39	0.4293
	A_1C	0.3-0.35	0.1116	0.1507	2.57	1.35	0.4747
	C	0.45-0.55	0.0736	0.0972	2.62	1.32	0.4961
	IIC	0.8-0.9	0.0858	0.1562	2.61	1.82	0.3027
	IIIC	1.3-1.4	0.1044	0.1869	2.65	1.79	0.3245
6	A_p	0.1-0.15	0.1483	0.2359	2.50	1.59	0.3640
	A_1	0.25-0.35	0.1228	0.2044	2.52	1.67	0.3393
	A_1C	0.4-0.5	0.1072	0.1718	2.61	1.66	0.3640
	C_{ca}	0.5-0.6	0.0902	0.1497	2.60	1.66	0.3615
	C_{1ca}	0.8-0.9	0.1004	0.1717	2.65	1.71	0.3547
	C_{2gca}	1.2-1.3	0.1153	0.2179	2.65	1.89	0.2868
	C_{3ca}	1.4-1.5	0.1262	0.2360	2.66	1.87	0.2970

Table 3. Some water properties of arable-humus horizons of the investigated soils

Number of profile	Hygroscopic water (H)		Max. hygroscopic capacity (MH)		Plastic Limit (W_p)	Liquid Limit (W_l)
	[kg·kg^{-1}]	[m^3·m^{-3}]	[kg·kg^{-1}]	[m^3·m^{-3}]	[kg·kg^{-1}]	[kg·kg^{-1}]
1	0.0184	0.0294	0.0546	0.0874	0.1407	0.2110
2	0.0171	0.0265	0.0510	0.0790	0.1281	0.2350
3	0.0624	0.0786	0.1615	0.2035	0.2852	0.5201
4	0.0601	0.0847	0.1561	0.2201	0.3030	0.5312
5	0.0279	0.0388	0.0741	0.1030	0.1766	0.3080
6	0.0188	0.0299	0.0436	0.0693	-	0.2155

Values for both of these traits varied considerably and depended clearly on the content of the clay fraction (R^2=0.978 for W_p ; R^2=0.976 for W_l) and ranged from W_p = 0.1281 kg·kg^{-3} (profile 2) and W_l = 0.2350 kg·kg^{-3} (profile 1) to W_p = 0.3030 kg·kg^{-3} and W_l = 0.5312 kg·kg^{-3} (profile 4). Likewise, texture and the content of $C_{org.}$ affected H (R^2=0.973) and MH (R^2=0.997, at α=0.05) (Tab. 3). Detailed data about properties determining the structure condition of the examined soils can be found in part ll of this study.

The analysed Phaeozems belong to semi-hydrogenic soils, i.e. formations whose origins were strongly influenced by a considerable humidification of their central and floor horizons. This favoured accumulation of organic matter in the upper horizons covered, in the past, by forest or grass vegetation. Their transfer into ploughing cultivation required, in the majority of cases, carrying out certain drainage operations which, as a rule, improved the air-water conditions of these soils but, at the same time, contributed to a slight subsidence of organic matter. In different soils, these processes followed and continue to follow different intensities which depend on the quantity and quality of the clay fraction as well as the presence of calcium carbonate because these compounds form with organic colloids stable mineral-organic complexes which exert a strong impact on soil physico-chemical parameters. That is why the highest quantities of organic carbon and total nitrogen were found in the soils of the ‘heaviest” texture of soils, i.e. in Gniew Phaeozems (Tab. 4). In the remaining examined soils, the determined levels of these valuable elements were slightly lower. The calculated C:N ratios, as a rule, fluctuating between 7.0 – 12.0, confirm variations in the biological activity (usually quite high) causing mineralisation of organic compounds.

Table 4. Basic chemical properties of investigated soils

Number of profile	Genetic horizon	Depth [m]	pH H_2O -	pH KCl -	Organic carbon [$g \cdot kg^{-1}$]	Total nitrogen [$g \cdot kg^{-1}$]	C:N -	$CaCO_3$ [$g \cdot kg^{-1}$]
1	A_p	0.1-0.2	7.89	7.44	16.0	1.9	8.4	9.0
	A_1	0.3-0.35	7.92	7.42	17.1	1.6	10.7	18.8
	A_1C_{ca}	0.5-0.6	8.23	7.60	17.6	1.7	10.4	64.0
	C_{ca}	0.7-0.8	8.41	7.86	0.7	-	-	85.3
2	A_p	0.1-0.2	7.88	7.48	18.4	1.4	13.1	9.4
	A_1C	0.35-0.4	8.14	7.60	5.9	1.0	5.9	10.2
	C_{ca}	0.8-0.9	8.45	8.02	1.6	-	-	209.0
3	A_p	0-0.2	7.72	7.06	23.8	1.9	12.5	4.3
	A_1C	0.35-0.4	7.55	6.82	13.9	1.2	11.6	2.2
	C_g	0.5-0.6	8.07	7.16	1.9	-	-	0.0
	C_{ca}	0.7-0.8	8.17	7.29	0.2	-	-	79.0
	C_{ca}	1.2-1.3	8.11	7.27	-	-	-	64.0
	IIC	1.4-1.5	8.33	7.37	-	-	-	66.1
4	A_p	0-0.35	7.87	7.09	19.9	1.7	11.7	21.0
	A_1C	0.5-0.6	7.97	7.06	11.0	0.9	12.2	12.8
	C_{cag}	1.1-1.2	8.23	7.25	0.5	-	-	25.6
5	A_p	0.05-0.15	7.98	7.48	19.0	2.2	8.6	0.0
	A_1C	0.3-0.35	8.17	7.63	6.7	0.9	7.4	2.2
	C	0.45-0.55	8.37	7.87	0.6	-	-	3.4
	IIC	0.8-0.9	8.52	7.90	0.1	-	-	3.0
	IIIC	1.3-1.4	8.44	7.86	-	-	-	4.6
6	A_p	0.1-0.15	7.66	7.30	19.8	1.8	11.0	2.3
	A_1	0.25-0.35	7.60	7.20	8.9	1.0	8.9	0.00
	A_1C	0.4-0.5	7.92	7.51	5.2	1.4	3.7	5.2
	C_{ca}	0.5-0.6	8.31	7.87	0.6	0.1	6.0	132.2
	C_{1ca}	0.8-0.9	8.38	7.93	-	-	-	98.1
	C_{2gca}	1.2-1.3	8.36	7.96	-	-	-	64.0
	C_{3ca}	1.4-1.5	8.34	7.78	-	-	-	89.6

Table 5. Electric conductivity (EC) and available macro-elements content

Number of profile/ horizon	EC [$dS \cdot m^{-1}$]	Macroelements P [$mg \cdot kg^{-1}$]	K	Mg
1. A_p	0.83	40.46	87.01	175.87
A_1	0.28	27.45	63.55	158.46
A_1C_{ca}	0.23	18.04	44.09	204.85
C_{ca}	0.29	11.64	32.21	244.77
2. A_p	0.31	33.72	72.11	186.33
A_1C	0.29	18.76	73.10	195.47
C_{ca}	0.30	12.92	59.38	190.76
3. A_p	0.38	40.81	90.91	171.33
A_1C	0.30	30.38	71.52	162.15
C_g	0.21	27.12	86.24	196.46
C_{ca}	0.28	12.88	77.76	194.88
C_{ca}	0.33	16.43	56.05	185.74
IIC	0.28	18.13	51.21	102.74
4. A_p	0.31	38.95	84.67	99.40
A_1C	0.34	29.17	62.45	90.88
C_{cag}	0.43	17.11	43.62	88.56
5. A_p	0.33	38.37	98.69	110.22
A_1C	0.34	34.52	91.30	101.14
C	0.30	16.78	76.83	187.96
IIC	0.22	17.13	82.01	193.79
IIIC	0.24	16.00	70.66	202.44
6. A_p	0.30	35.59	67.71	211.83
A_1	0.59	26.01	75.34	283.99
A_1C	0.47	19.57	42.18	312.28
C_{ca}	0.32	16.32	47.01	265.82
C_{1ca}	0.21	16.61	33.09	176.16
C_{2gca}	0.21	15.41	32.65	189.20
C_{3ca}	0.22	14.48	32.21	175.13

The basic or, less frequently, neutral reaction of the examined soils was the result of the presence in the parent material of the examined profiles of different quantities of natural calcium carbonate (Tab. 4). This confirms considerable buffer capacity and, indirectly, also high "natural" resistance of these soils to degradation processes. This is further corroborated by the sorption capacities of the examined soils which should be evaluated as high [10]. The highest total sorption capacity (CEC) was determined in the Gniew Phaeozems followed by Phaeozems from the area of Wrocław, Inowrocław and Środa (Tab. 6). A very high degree of saturation (BS), observed in all profiles, of the sorption complex with alkaline cations (TEB) should be assessed as exceptionally favourable for the growth and development of crop plants. At the moment, these soils do not require liming. The determined EC values indicate unequivocally that soils under investigations do not show salinity (Tab. 5). The quantities of the available forms of macroelements, albeit very diverse, allow to classify majority of the upper horizons of these soils to high and very high magnesium fertility and low and very low potassium and phosphorus fertility classes. This can indicate a strong retrogression of these elements as a result of potassium binding in the crystalline networks of clay minerals (potassium fixation) and formation of poorly soluble calcium orthophosphates.

Summary

The above presented results of the basic physical and chemical properties of selected profiles of Phaeozems from

Table 6. Basic characteristic of sorptive complex

Number of profile/ horizon	TEB	H_h	CEC	BS
	[cmol$^{(+)}$·kg^{-1}]			[%]
1. A_p	15.52	0.42	15.94	97.36
A_1	16.94	0.40	17.34	97.69
A_1C_{ca}	18.45	0.45	18.90	97.62
C_{ca}	9.61	0.41	10.02	95.91
2. A_p	16.56	0.45	17.01	97.36
A_1C	11.92	0.40	12.32	96.75
C_{ca}	9.33	0.45	9.78	95.40
3. A_p	34.54	0.75	35.29	97.87
A_1C	31.84	0.77	32.61	97.64
C_g	23.14	0.53	23.67	97.76
C_{ca}	21.74	0.44	22.18	98.02
C_{ca}	21.95	0.45	22.40	97.99
IIC	14.75	0.45	15.20	97.04
4. A_p	33.43	0.46	33.89	98.64
A_1C	29.71	0.53	30.24	98.25
C_{cag}	26.70	0.53	27.23	98.05
5. A_p	20.91	0.46	21.37	97.85
A_1C	13.97	0.54	14.51	96.28
C	9.18	0.45	9.63	95.33
IIC	6.87	0.30	7.17	95.82
IIIC	7.58	0.42	8.00	94.75
6. A_p	15.76	0.68	16.44	95.86
A_1	10.88	0.53	11.41	95.35
A_1C	8.67	0.40	9.07	95.59
C_{ca}	5.54	0.40	5.94	93.27
C_{1ca}	4.77	0.43	5.20	91.73
C_{2gca}	5.18	0.42	5.60	92.50
C_{3ca}	7.60	0.40	8.00	95.00

different parts of Poland allow to draw a number of generalizations. All the analyzed soil pits belong to soils potentially rich in nutrients and are characterized by the reaction close to neutral which makes it possible to cultivate on them the most valuable crop plants. Nevertheless, the examined soils differ from one another with regard to their fertility owing to quite changeable air-water parameters which depend on their texture. The exceptionally heavy texture of the Gniew Phaeozems make them frequently excessively wet during spring which delays the initiation of field works (the so called “minute soils”). On the other hand, during dry years, these soils undergo strong encrustation and contraction which, in turn, leads to the development of numerous cracks in their upper horizons. They can reach 8-10 cm in width and can be 40 – 50 cm deep, frequently damaging root systems of the cultivated crop plants. The above-mentioned characteristics of the Gniew Phaeozems contribute to the fact that, despite their very high content of silicates and aluminium silicates, with respect to the quality class they are allocated only to IVa and IVb classes. Wrocław, Kujawy and Środa Phaeozems are characterised by higher agricultural value (IIIa and IIIb and sometimes II classes). They are fully suitable not only for conventional agriculture but also for ecological farming.

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