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ESTIMATION OF CATION EXCHANGE CAPACITY AND CATION SATURATION OF LUVISOLS DEVELOPED FROM LOESS

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Abstract

The cation exchange capacity and saturation of the sorptive complex with base cations are very important indicators for quality assessment of soils, because they define soil fertility and resistance to chemical degradation. The objective of the following study was to estimate the cation exchange capacity and saturation with exchangeable cations of Luvisols developed from loess, under agricultural use. The study comprised 12 pedons under winter wheat culture, classified into various complexes of soil suitability. Exchangeable cations of alkaline character were assayed with the Pallmann method in 1 mol NH_4Cl dm^{-3} extract with pH 8.2. The content of cations Ca^{2+}, K^+ and Na^+ was determined with a flame photometer, while that of Mg^{2+} was measured with the AAS method. In the Ap horizons of the analyzed soils, the quantitative sequence of base cations was most frequently Ca^{2+}>Mg^{2+}>K^+>Na^+. The total exchange bases (TEB) was favourable in most of the soils (3.8-16.9 cmol(+) kg^{-1}), and the total acidity (TA) was varied (0.5-3.7 cmol(+) kg^{-1}) but generally low. The cation exchange capacity (CEC) in the Ap, Et, EB, Bt and BC horizons of the soils was assessed as medium or high (5.2-17.9 cmol(+) kg^{-1}). Only the C horizon, containing calcium carbonate, was characterised by very high CEC (76.2 cmol(+) kg^{-1}). The base saturation (BS) was highly favourable in most of the soils (62.9-99.4%) and increased deeper into the pedon. The soils were characterised by generally favourable shares of particular cations: the percentage of Ca^{2+} was 51.5-95.1%, most often higher than the optimum, while the shares of Mg^{2+} and K^+ were slightly below the optimum. The calculated quantitative ratios between the cations showed very strong variation of values among particular pedons. The content of Mg^{2+} cations and the values of TEB and CEC in the Ap horizons of soils from the very good wheat complex were lower than in the Ap horizons of soils from the good wheat complex and the deficient wheat complex, whereas the levels of Ca^{2+}, K^+, Na^+ and H^+ as well as BS displayed only minor differences.

Key words: Luvisols developed from loess, cation exchange capacity, exchangeable cations.

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OCENA POJEMNOŚCI WYMIANY KATIONÓW I WYSYCENIA KATIONAMI GLEB PŁOWYCH WYTWORZONYCH Z LESSU

Abstrakt

Pojemność wymiany kationów i wysycenie kompleksu sorpcyjnego kationami zasadowymi są bardzo ważnymi wskaźnikami jakości gleb, ponieważ decydują o ich żyzności i odporności na degradację chemiczną. Celem pracy była ocena pojemności wymiany kationów i wysycenia kationami wymiennymi intensywnie użytkowanych rolniczo gleb płowych wytworzonych z lessu. Badaniami objęto 12 pedonów pod uprawą pszenicy ozimej, zaliczanych do różnych kompleksów przydatności rolniczej. Kationy wymienne o charakterze zasadowym oznaczono metodą Pallmanna w wyciągu 1 mol NH_4Cl dm^{-3} o pH 8,2. Zawartość kationów Ca^{2+}, K^+ i Na^+ oznaczono na fotometrze płomieniowym, natomiast zawartość kationów Mg^{2+} – metodą AAS. W poziomach Ap badanych gleb szereg ilościowy kationów zasadowych kształtował się najczęściej jako $Ca^{2+}>Mg^{2+}>K^+>Na^+$. Suma kationów zasadowych była w większości gleb korzystna (3,8-16,9 cmol(+) kg^{-1}), a kwasowość hydrolityczna zróżnicowana (0,5-3,7 cmol(+) kg^{-1}), ale najczęściej mała. Pojemność wymiany kationów w poziomach Ap, Et, EB, Bt i BC badanych gleb oceniono jako średnią lub dużą (5,2-17,9 cmol(+) kg^{-1}). Tylko w poziomie C zawierającym węglan wapnia wykazano bardzo dużą pojemność (76,2 cmol(+) kg^{-1}). Stopień wysycenia kationami zasadowymi był w większości badanych gleb bardzo korzystny (62,9-99,4%) i wzrastał wraz z głębokością pedonu. W badanych glebach stwierdzono ogólnie korzystny udział poszczególnych kationów: udział Ca^{2+} wynosił 51,5-95,1% i był najczęściej większy od optymalnego, natomiast udział Mg^{2+} i K^+ był nieco mniejszy od optymalnego. Obliczone stosunki ilościowe między kationami wykazywały bardzo duże zróżnicowanie wartości w poszczególnych pedonach. Zawartość kationów Mg^{2+}, suma kationów zasadowych i pojemność wymiany kationów w poziomach Ap gleb kompleksu pszennego bardzo dobrego była mniejsza niż w poziomach Ap gleb kompleksu pszennego dobrego i pszennego wadliwego, natomiast zawartość Ca^{2+}, K^+, Na^+ i H^+ oraz wysycenie zasadami wykazywały tylko nieznaczne różnice.

Słowa kluczowe: gleby płowe wytworzone z lessu, pojemność wymiany kationów, kationy wymienne.

INTRODUCTION

Soil ability of exchangeable adsorption of cations, the measure of which is the cation exchange capacity (CEC), is a very important indicator for the estimation of soil quality. The value of CEC is determined by the sum of cations which neutralise negative charges on the surface of soil colloids, and by the soil reaction (PEINEMANN et al. 2000, KAISER 2008, RASHIDI, SEILSEPOUR 2008). An equally important indicator of soil quality is its degree of saturation with base cations: Ca^{2+}, Mg^{2+}, K^+ and Na^+. The higher the level of saturation with exchangeable bases, the lower the share of cations H^+ and Al^{3+} determining the total acidity of the soil. The level of saturation of the sorptive complex with base cations determines the fertility of soils and their resistance to chemical degradation. Depending on the soil reaction and relative shares and kinds of dominant mineral and organic colloids, various quantitative ratios appear in the soil among the particular cations taking part in the ionic exchange (STEVENS et al. 2005, KOPITTKE, MENZIES 2007, SZYMAŃSKA et al. 2007). The content of base and acidic exchangeable cations in the sorptive complex of soil has an effect on plant nutrition and on the status of ionic balance in plants. Cations adsorbed in soil colloids constitute a pool of nutrients for plants.

Particular types and kinds of soils differ in the degree to which the cation exchange capacity is utilized by base and acidic cations (Drozd et al. 2007, Szafranek et al. 2007, Kalembasa et al. 2011, Kobierski et al. 2011). Intensive agricultural use of soils may cause both enrichment and impoverishment of the sorptive complex in base cations (Stojek 2005, Koćmit et al. 2008, Rychcik et al. 2008). The objective of the study was to estimate the cation exchange capacity and the saturation with exchangeable cations of Luvisols developed from loess, under intensive agricultural use, classified to various complexes of agricultural suitability.

MATERIAL AND METHODS

Field studies on Luvisols developed from loess were conducted on 4 selected pedons each, classified into three complexes of agricultural suitability of arable soils: the very good wheat complex (1), the good wheat complex (2) and the deficient wheat complex (3). In total, the study comprised 12 Luvisols under winter wheat cultivation, situated in various mesoregions of the Lublin Upland and the Volyn Upland (Kondracki 2002) – Figure 1:

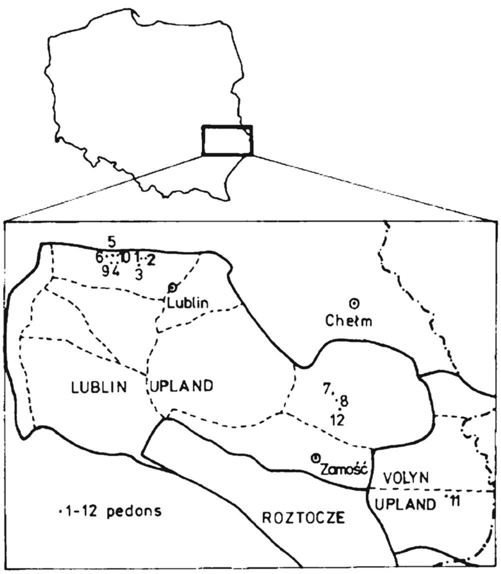

Fig. 1. Map of the location of the pedons

a) Luvisols classified into the very good wheat (1) complex of agricultural suitability and II valuation class, No.: 1 – Piotrawin, 51°19′39″N, 22°26′4″E, 2 – Jastków Kolonia, 51°19′40″N, 22°26′28″E, 3 – Tomaszowice, 51°17′9″N, 22°26′10″E, 4 – Ługów, 51°19′25″N, 22°18′33″E (Nałęczów Plateau);

b) Luvisols classified into the good wheat (2) complex of agricultural suitability and IIIa-IIIb valuation class, No.: 5 – Gutanów, 51°20′45″N, 22°17′42″E, 6 – Ludwinów, 51°20′15″N, 22°16′55″E (Nałęczów Plateau), 7 – Wólka Kraśniczyńska, 50°55′19″N, 23°22′19″E, 8 – Drewniki 50°54′26″N, 23°22′53″E (Grabowiec Plateau);

c) Luvisols classified into the deficient wheat (3) complex of agricultural suitability and IVa-IVb valuation class, No.: 9 – Kolonia Ługów, 51°19′31″N, 22°18′37″E, 10 – Kolonia Gutanów, 51°21′4″N, 22°18′37″E (Nałęczów Plateau), 11 – Poturzyn, 50°33′56″N, 23°54′55″E (Sokal Plateau), 12 – Majdan Skierbieszowski, 50°53′20″N, 23°23′16″E (Grabowiec Plateau).

The soils selected for the study lay in individual farms, where the share of cereals in crop rotation was most often 75%. The soils were characterised by varied, but generally fairly low, levels of organic fertilisation, consisting only of straw plough-over, and less frequently the application of farmyard manure. The level of mineral fertilisation of the soils was higher than that of organic fertilisation, but it was also varied and biased towards nitrogen fertilisers. Most of the soils studied were limed too rarely, and on some (pedons Nos 4, 5 and 12) no calcium fertilisers had been applied for twenty years.

Soil samples for laboratory analyses were taken in August, when wheat was in the phase of full ripeness or shortly after its harvest, from four layers of the pedons with depths of: 0-25 cm (from Ap horizon), 25-50 cm (from Et, EB, Bt1 or Bt2horizons), 50-75 cm (from Bt1, Bt2 or BC horizons) and 75-100 cm (from Bt2, BC or C horizons). In total, 48 soil samples were taken and subjected to laboratory analyses.

The texture of the soils was determined with the Casagrande areometric method modified by Prószyński, separating the sand sub-fraction on sieves with mesh sizes of 1, 0.5, 0.25 and 0.1 mm. The particle-size groups were determined in accordance with the classification of the Polish Society of Soil Science of 2008 (5th Commission ... 2011). The content of total organic carbon (TOC) was assayed at the IUNG Central Laboratory of Chemical Analyses in Puławy, using an analyser Vario Max CNS Elementar. Soil pH in 1 mol KCl dm^{-3} was measured potentiometrically with a combined electrode.

Total acidity (TA) in cmol H^+ kg^{-1} was assayed with the Kappen method in 1 mol CH_3COONa dm^{-3}. The level of base exchangeable cations in cmol(+) kg^{-1} was assayed with the Pallmann method in 1 mol NH_4Cl dm^{-3} extract with pH 8.2. The content of exchangeable cations Ca^{2+}, K^+ and Na^+ was determined on a flame photometer, and the content of cations Mg^{2+} – with the method of atomic absorption spectroscopy (AAS). Based on those assays, the following were calculated: sum of base cations (TEB) and cation exchange capacity (CEC) in cmol(+) kg^{-1}, degree of saturation of the sorptive complex with base cations (BS) in percentages, shares of individual cations in the sorptive complex of soil, and their molar ratios.

The results were subjected to statistical analysis. Calculations were made of the coefficients of simple correlation (*r*) between the content of particle-size fractions, content of TOC and physicochemical properties of all soil horizons, using the program Statistica 7.

RESULTS AND DISCUSSION

The Luvisols developed from loess classified into the very good wheat complex contained 13-14% of sand fraction (2-0.05 mm), 78-79% of silt (0.05-0.002 mm) and 7-8% of clay (<0.002 mm) in the Ap horizon (0-25 cm) – Table 1. Similar texture was found in the Et horizons, while the EB and Bt horizons had a higher content of clay (14-24%) and lower of silt (63-71%). Soils from the good wheat complex and deficient wheat complex had a higher content of clay (8-19%) and a lower level of silt (70-75%) in their Ap horizons. Only soil No. 7, in the 0-80 cm horizon, had a lower content of silt (52-62%) and a higher of sand (29-30%) compared to the other soils. In terms of their particle-size distribution, the soils were most frequently loamy silts or clayey silts.

The content of total organic carbon (TOC) in the Ap horizons of the first complex soils was 6.36-9.48 g kg^{-1} and it was only slightly higher than in soils from complexes two and three (4.68-7.50 g kg^{-1}). The subsurface horizons Et, Bt, BC and C contained only 0.72-3.36 g kg^{-1} of TOC (Table 1). The reaction of the Ap horizons of the examined soils was most often weakly acidic (pH 5.6-6.2), less frequently acidic (pH 4.7-5.5) or strongly acidic (pH 4.1-4.5). The reaction of the Et, Bt and BC horizons was most often acidic, less frequently weakly acidic or strongly acidic. Only the C horizon, containing calcium carbonate, was alkaline in reaction (pH 7.3). Acidification of the soils from complex 1 was slightly greater than of those from complexes 2 and 3.

Total acidity (TA) in the Ap horizons of the soils was 0.8-3.7 cmol(+) kg^{-1}, and 0.5-3.0 cmol(+) kg^{-1}in the subsurface horizons. Differences in TA among the soils classified into various soil suitability complexes were small (Table 2). TA did not display any significant relation to the content of the particle-size fractions and of TOC, but it was closely negatively correlated with the value of pH (r=-0.73) – Table 3.

The composition of exchangeable cations of the soils was dominated by calcium cations (Table 2). In the Ap horizons of soils from complex 1, the content of cations Ca^{2+} was 3.1-10.4 cmol(+) kg^{-1} and it was slightly lower than in the Ap horizons of soils from complexes 2 (3.0-10.9 cmol(+) kg^{-1}) and

Table 1

Texture and selected properties of the soils

Soil complex	Pedon No.	Horizon	Depth (cm)	Sampling depth (cm)	Particle size fraction (%) in mm			TOC (g kg^{-1})	pH KCl
					2-0.05	0.05-0.002	<0.002		
1 Very good wheat	1	Ap	0-30	5-15	14	78	8	9.48	4.7
		EB	30-40	30-40	13	68	19	3.36	4.6
		Bt1	40-67	55-65	16	63	21	1.74	4.5
		Bt2	67-102	80-90	14	68	18	1.44	4.6
	2	Ap	0-30	5-15	13	79	8	7.56	5.3
		EB	30-35	30-35	16	66	18	1.80	5.1
		Bt1	35-63	55-60	16	65	19	0.84	5.3
		Bt2	63-100	80-90	16	70	14	1.32	5.4
	3	Ap	0-30	5-15	14	78	8	8.34	6.2
		Et	30-48	30-40	13	76	11	3.30	5.8
		Bt1	48-75	55-65	12	64	24	1.68	5.2
		Bt2	75-113	80-90	12	68	20	0.90	5.2
	4	Ap	0-30	5-15	14	79	7	6.36	4.3
		Et	30-43	30-40	15	73	12	0.90	4.5
		Bt1	43-65	55-65	16	66	18	1.98	4.6
		Bt2	65-105	80-90	12	71	17	1.86	4.8
2 Good wheat	5	Ap	0-24	5-15	16	75	9	6.12	4.5
		EB	24-38	30-40	15	71	14	1.92	5.2
		Bt1	38-75	55-65	14	63	23	1.08	5.4
		Bt2	75-103	80-90	15	67	18	0.90	4.6
	6	Ap	0-27	5-15	14	70	16	6.60	6.2
		Bt1	27-49	30-40	15	63	22	1.92	5.4
		Bt2	49-78	55-65	13	71	16	1.32	5.8
		BC	78-101	80-90	14	73	13	0.72	6.1
	7	Ap	0-25	5-15	30	62	8	6.90	5.5
		EB	25-42	30-40	30	53	17	2.52	5.0
		Bt1	42-80	55-65	29	52	19	0.72	5.7
		Bt2	80-108	80-90	18	58	24	0.90	5.8
	8	Ap	0-24	5-15	14	70	16	6.48	5.8
		Bt1	24-60	30-40	12	61	27	1.44	5.4
		Bt2	60-80	60-70	13	62	25	1.14	4.3
		BC	80-111	80-90	29	51	20	0.72	4.2
3 Deficient wheat	9	Ap	0-25	5-15	14	71	15	7.14	6.1
		Bt2	25-40	30-40	16	70	14	1.20	5.9
		BC	40-75	55-65	17	70	13	1.38	6.1
		Cca	>75	80-90	16	73	11	1.08	7.3
	10	Ap	0-26	5-15	13	71	16	7.50	5.8
		Bt1	26-45	30-40	13	71	16	2.52	5.8
		Bt2	45-70	55-65	16	70	14	1.32	6.1
		BC	70-104	80-90	15	71	14	0.84	5.9
	11	Ap	0-25	5-15	11	70	19	4.68	5.6
		Bt1	25-46	30-40	13	66	21	2.40	5.2
		Bt2	46-65	55-65	13	70	17	2.16	5.2
		BC	65-100	80-90	11	74	15	0.72	5.4
	12	Ap	0-18	5-15	14	68	18	6.18	4.1
		Bt1	18-45	30-40	13	67	20	1.80	4.3
		Bt2	45-80	55-65	12	71	17	1.44	4.4
		BC	80-115	80-90	15	69	16	2.40	4.5

3 (6.8-13.0 cmol(+) kg^{-1}). The content of calcium cations increased slightly in the Bt horizons (5.5-14.1 cmol(+) kg^{-1}), while the highest values were attained in the C horizon – 72.4 cmol(+) kg^{-1}. Within the soil pedons studied, calcium cations correlated closely and positively with the pH value of the soils (r=0.53) – Table 3.

The content of Mg^{2+} cations in the Ap horizons of soils from the very good wheat complex was 0.5-1.0 cmol(+) kg^{-1} and it was somewhat lower than in the Ap horizons of soils from the good wheat complex (0.5-1.3 cmol(+) kg^{-1}) and deficient wheat complex (1.4-1.7 cmol(+) kg^{-1}). The content of magnesium cations increased slightly with depth, and in the Bt, BC and C horizons it equalled 1.0-2.8 cmol(+) kg^{-1} (Table 2). Magnesium cations correlated closely and positively with the content of clay (r=0.72) and weakly with the content of cations Ca^{2+} (r=0.29) – Table 3.

The content of K^+ cations in the soils was slightly varied and equalled 0.1-0.6 cmol(+) kg^{-1} (Table 2). The highest values of 0.5-0.6 cmol(+) kg^{-1} in the Ap horizons of soils assigned numbers 2, 7 and 8 were caused by the application of potassium fertilisers. The content of exchangeable cations Na^+ was most frequently at the level of 0.1-0.5 cmol(+) kg^{-1}, with the exception of the C horizon, where it reached 1.4 cmol(+) kg^{-1}. Potassium cations correlated closely and positively with the content of TOC (r=0.40) and with hydrolytic acidity (r=0.43), while sodium cations correlated with the value of pH (r=0.48), calcium cations (r=0.97) and magnesium cations (r=0.40) – Table 3.

In the Ap horizons of the soils, the quantitative sequence of base cations was most often Ca^{2+}>Mg^{2+}>K^+>Na^+, which is characteristic for most mineral soils of Poland (Jaworska et al. 2008, Kalembasa et al. 2011, Kobierski et al. 2011). Whereas, in the subsurface horizons of the soils, the sequence of Ca^{2+}>Mg^{2+}>Na^+>K^+ was frequently found. Especially in loess rock, sodium cations tend to appear in larger amounts than potassium cations (Uziak et al. 2004).

Total exchange bases (TEB) in the Ap horizons of soils from complex 1 was 3.9-11.8 cmol(+) kg^{-1} and it was only slightly lower than in soils from complexes 2 (3.8-12.6 cmol(+) kg^{-1}) and 3 (8.8-14.9 cmol(+) kg^{-1}). In the Bt and BC horizons, the total bases ranged from 7.2 to16.9 cmol(+) kg^{-1}, and in the C horizon it increased to 75.7 cmol(+) kg^{-1} (Table 2). TEB was closely and positively correlated with the value of pH (r=0.52), calcium cations (r=0.99) and sodium cations (r=0.97), and weakly positively correlated with magnesium cations (r=0.34) – Table 3.

Cation exchange capacity (CEC) in the Ap horizons of soils from the very good wheat complex was in the range of 6.1-12.7 cmol(+) kg^{-1}, and it was only slightly lower than in soils from the good wheat complex (5.2-13.4 cmol(+) kg^{-1}) and deficient wheat complex (11.1-15.7 cmol(+) kg^{-1}). In the Bt and BC horizons, CEC was 8.2-17.9 cmol(+) kg^{-1}, and in the parent rock C it increased to 76.7 cmol(+) kg^{-1} (Table 2). CEC displayed the same correlations as TEB, namely it was closely and positively correlated with pH (r=0.47), content of

Table 2

Content of exchangeable cations and sorptive capacity parameters

Soil complex	Pedon No.	Hori-zon	TA	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	TEB	CEC	BS (%)	TA	Ca^{2+}	Mg^{2+}	K^{+}
			(cmol(+) kg^{-1})								(%)			
1 Very good wheat	1	Ap	1.5	4.3	0.5	0.3	0.1	5.2	6.7	77.4	22.6	65.0	6.8	4.1
		EB	1.9	6.8	0.7	0.2	0.2	7.8	9.7	80.7	19.3	69.6	6.8	2.5
		Bt1	1.8	7.0	1.3	0.3	0.2	8.8	10.6	82.9	17.1	66.1	12.5	2.7
		Bt2	1.5	6.2	1.3	0.3	0.1	7.9	9.4	84.0	16.0	65.8	13.6	2.9
	2	Ap	1.4	5.1	0.5	0.6	0.1	6.3	7.7	81.6	18.4	66.6	5.9	7.4
		EB	1.3	7.4	0.8	0.3	0.2	8.7	10.0	87.1	12.9	74.2	7.9	3.1
		Bt1	1.4	8.3	1.4	0.2	0.2	10.1	11.5	88.3	11.7	72.6	12.2	1.9
		Bt2	1.0	6.0	1.3	0.2	0.1	7.6	8.6	87.8	12.2	69.6	14.8	1.8
	3	Ap	0.9	10.4	1.0	0.2	0.2	11.8	12.7	92.9	7.1	82.0	7.8	1.2
		Et	1.0	6.0	0.5	0.1	0.2	6.8	7.8	86.6	13.4	76.8	6.3	1.2
		Bt1	0.8	10.3	1.3	0.2	0.3	12.1	12.9	93.6	6.4	79.9	9.9	1.7
		Bt2	1.3	7.7	1.4	0.2	0.2	9.5	10.8	88.2	11.8	71.3	13.3	1.8
	4	Ap	2.2	3.1	0.5	0.2	0.1	3.9	6.1	62.9	37.1	51.5	7.4	2.6
		Et	1.5	4.3	0.6	0.1	0.1	5.1	6.6	77.4	22.6	65.2	8.4	2.0
		Bt1	1.4	6.8	1.4	0.2	0.2	8.6	10.0	86.5	13.5	68.3	14.4	2.0
		Bt2	0.9	5.5	1.4	0.2	0.1	7.2	8.1	88.9	11.1	67.8	17.3	2.1
2 Good wheat	5	Ap	1.4	3.0	0.5	0.2	0.1	3.8	5.2	74.0	26.0	58.3	9.5	4.5
		EB	1.3	6.2	0.7	0.2	0.3	7.4	8.7	85.1	14.9	72.3	7.7	1.8
		Bt1	1.3	9.4	1.2	0.2	0.2	11.0	12.3	89.6	10.4	76.1	10.0	1.6
		Bt2	1.0	6.8	1.2	0.2	0.2	8.4	9.4	89.5	10.5	73.3	12.4	1.8
	6	Ap	0.8	10.9	1.2	0.2	0.3	12.6	13.4	94.4	5.6	81.4	9.2	1.8
		Bt1	1.1	10.2	1.4	0.2	0.3	12.1	13.2	91.5	8.5	77.3	10.6	1.7
		Bt2	1.0	7.7	1.2	0.2	0.2	9.3	10.3	90.5	9.5	75.0	12.0	1.7
		BC	0.6	6.3	1.0	0.1	0.2	7.6	8.2	92.7	7.3	76.7	12.5	1.6
	7	Ap	1.8	4.8	0.8	0.5	0.2	6.3	8.1	77.6	22.4	59.4	10.3	5.7
		EB	2.3	7.4	1.1	0.3	0.2	9.0	11.3	80.1	19,9	65.4	9.8	2.7
		Bt1	1.1	9.7	1.1	0.2	0.3	11.3	12.4	91.5	8.5	78.2	8.8	1.9
		Bt2	1.0	14.1	2.1	0.2	0.5	16.9	17.9	94.1	5.9	78.4	11.5	1.3
	8	Ap	1.7	8.3	1.3	0.5	0.2	10.3	12.0	86.2	13.8	69.6	11.0	3.7
		Bt1	1.7	11.4	2.7	0.4	0.3	14.8	16.5	90.0	10.0	69.3	16.4	2.4
		Bt2	2.3	9.3	2.8	0.3	0.3	12.7	15.0	84.6	15.4	62.0	18.6	1.9
		BC	2.2	7.8	2.3	0.3	0.3	10.7	12.9	82.5	17.5	60.6	17.9	2.0
3 Deficient wheat	9	Ap	0.8	13.0	1.4	0.2	0.3	14.9	15.7	94.8	5.2	82.4	8.9	1.6
		Bt2	1.0	7.3	1.0	0.2	0.2	8.7	9.7	89.9	10.1	75.8	10.6	1.4
		BC	0.8	13.0	1.6	0.2	0.3	15.1	15.9	94.8	5.2	81.6	10.1	1.0
		Cca	0.5	72.4	1.7	0.2	1.4	75.7	76.2	99.4	0.6	95.1	2.3	0.2
	10	Ap	1.0	8.3	1.4	0.2	0.2	10.1	11.1	91.2	8.8	75.2	12.2	1.8
		Bt1	0.6	8.3	1.0	0.2	0.2	9.7	10.3	94.2	5.8	80.9	9.6	1.5
		Bt2	0.8	6.9	1.0	0.1	0.2	8.2	9.0	91.6	8.4	77.3	11.0	1.5
		BC	0.8	6.4	1.2	0.1	0.2	7.9	8.7	90.6	9.4	73.5	13.7	1.7
	11	Ap	1.5	11.0	1.7	0.3	0.3	13.3	14.8	89.9	10.1	74.4	11.1	2.3
		Bt1	1.2	11.5	1.9	0.3	0.4	14.1	15.3	92.1	7.9	75.6	12.1	1.9
		Bt2	1.0	8.9	1.4	0.3	0.3	10.9	11.9	91.2	8.8	75.0	11.4	2.1
		BC	0.7	8.3	1.3	0.3	0.3	10.2	10.9	93.7	6.3	77.0	11.8	2.3
	12	Ap	3.7	6.8	1.5	0.3	0.2	8.8	12.5	70.6	29.4	54.3	11.8	2.7
		Bt1	3.0	8.3	1.6	0.3	0.3	10.5	13.5	77.8	22.2	61.6	12.2	2.1
		Bt2	2.2	7.2	1.5	0.3	0.2	9.2	11.4	80.9	19.1	63.2	13.3	2.2
		BC	1.8	6.3	1.4	0.3	0.2	8.2	10.0	81.9	18.1	63.3	14.0	2.3

Table 3

Correlations coefficients between investigated properties of soils (n=48)

Variable	TA	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	CEC	BS
2-0.05	0.17	0.00	-0.01	0.15	0.05	0.00	0.01	-0.15
0.05-0.002	-0.26	0.01	-0.53**	-0.19	-0.12	-0.02	-0.04	-0.10
<0.002	0.17	-0.02	0.72**	0.11	0.10	0.03	0.04	0.28
TOC	0.15	-0.14	-0.38**	0.40**	-0.20	-0.15	-0.15	-0.33*
pH KCl	-0.73**	0.53**	-0.08	-0.19	0.48**	0.52**	0.47**	0.74**
TA	1	-0.26	0.18	0.43**	-0.21	-0.25	-0.19	-0.79**
Ca^{2+}		1	0.29*	-0.09	0.97**	0.99**	0.99**	0.42**
Mg^{2+}			1	0.16	0.40**	0.34*	0.35*	0.33*
K^+				1	-0.04	-0.07	-0.04	-0.26
Na^+					1	0.97**	0.97**	0.45**
TEB						1	0.99**	0.43**
CEC							1	0.39**
BS								1

* significance level 0.05, ** significance level 0.01

cations Ca^{2+} (r=0.99), Na^+ (r=0.97), and weakly correlated with cations Mg^{2+} (r=0.35) – Table 3. CEC values in the Ap horizons of soils classified in complexes 1 and 2 were most frequently assessed as medium or high, and most often as high in the Ap horizons of soils from complex 3 and in the Bt and BC horizons. In the soils from complex 3 (pedons 9-12), situated on loess slopes with considerable inclination, the Ap horizons developed as a result of erosion from the illuvial Bt horizon, and therefore had a higher content of clay and higher CEC. It was only the C horizon, containing calcium carbonate, that was characterised by very high CEC.

The Luvisols developed from loess were characterised by higher CEC compared to Luvisols developed from loamy sands and to Brunic Arenosols and Podzols soils developed from weakly loamy sands (Stojek 2005). CEC values similar to those of the soils under study were found for Luvisols developed from boulder loams (Szafranek et al. 2007, Kobierski et al. 2011). Compared to Chernozems developed from loess (Drozd et al. 2007), Phaeozems developed from loams (Koćmit et al. 2008) and alluvial soils (Bartkowiak, Długosz 2010), the CEC values of the soils studied were lower.

The degree of saturation of the sorptive complex with base cations (BS) in the Ap horizons of the analyzed soils was varied (62.9-94.8%). BS increased with depth and reached 77.8-94.1%, in the Bt horizons, 81.9-94.8% in the BC horizons and 99.4%. in the C horizon (Table 2). BS did not display any variation with relation to the soil suitability complex. The BS was closely and positively correlated with the pH value of the soils (r=0.74), cations Ca^{2+} (r=0.42), Na^+ (r=45), TEB (r=0.43) and CEC (r=0.39), and weakly correlated with cations Mg^{2+} (r=0.33) – Table 3. BS was highly favourable in most of the studied Luvisols, despite their acidic or strongly acidic reaction. This indicates very good buffering properties of Luvisols developed from loess. The lowest values of TEB, CEC and BS noted in pedons 3, 6 and 9 result from the application of calcium fertilisers. Whereas, the lowest degree of BS in the Ap horizons of pedons 4, 5 and 12 was due to the lack of liming and strongly acidic reaction of those soils.

The Luvisols developed from loess were characterised by considerable variation in contributions of particular cations to the saturation of the sorptive complex (Table 2). Saturation with cations Ca^{2+} in the Ap horizons was 51.5-82.4%, in the Et, EB, Bt and BC horizons – 61.6-81.6%, and in the C horizon – as much as 95.1% (Table 4). The share of cations Mg^{2+} in the Ap horizons varied within the range of 5.9-12.2%, while in the subsurface horizons it was 2.3-18.6%. Saturation with cations K^+ in the Ap horizons was 1.2-7.4%, and in the subsurface horizons – 0.2-3.1%. Saturation with sodium cations constituted 1.4-2.2% of the sorptive complex in the Ap horizons of the soils, and 1.6-3.2% in the deeper horizons. The share of total acidity (cations H^+) in the sorptive complex of the Ap horizons had a wider range: 5.2-37.1%. Most frequently, the share of cations H+ decreased with the depth in the pedons to the level of 8.7-12.9% in the BC horizon and 0.6% in the C horizon. No significant differences were noted in the saturation with particular cations between pedons classified in different soil suitability complexes.

The percentages of particular cations are important for an assessment of the capability of soil to supply plants with nutrients and to provide optimum conditions for their growth. The concept of optimum saturation of soils with cations, generally accepted for a long time, presumes that their respective shares should be *ca.* 65% Ca^{2+}, 15% Mg^{2+}, 5% K^+ and no more than 15-20% H^+. However, numerous studies indicate that the concept does not apply to all soils and all crops (Stevens et al. 2005, Kopittke, Menzies 2007). In the Ap and Et horizons of the studied Luvisols, the share of magnesium was lower than the optimum, unlike the share of calcium cations, which was higher. Despite those differences, most of the studied Luvisols were characterised by favourable shares of particular cations, irrespective of the soil suitability complex. The notable level of cations H^+ in the Ap horizons of pedons 4, 5 and 12 (25.0-37.1%) and their strongly acidic reaction resulted from long-term absence of liming, and indicated very weak chemical degradation of those soils. Nitrogen fertilisation is an additional factor contributing to the acidification of soils and causing a reduction in the shares of cations Ca^{2+} and Mg^{2+} (Szymańska et al. 2007).

The differences in the per cent shares of particular cations resulted in different molar ratios between them. The ratios between the following cations: $Ca^{2+}+Mg^{2+}/K^++Na^+$, Ca^{2+}/Mg^{2+}, Ca^{2+}/K^+ and Mg^{2+}/K^+ are used as criteria in estimation of the sorptive complex quality of soils (Stevens et al. 2005, Szymańska et al. 2007, Bartkowiak, Długosz 2010, Kalembasa et al. 2011). The ratios calculated herein indicated very strong differentiation of values

Table 4

Basic cation saturation ratios in the sorption complex of soils

Horizon	$Ca^{2+}+Mg^{2+}$/ $K^{+}+Na^{+}$	Ca^{2+}/Mg^{2+}	Ca^{2+}/K^{+}	Mg^{2+}/K^{+}
Ap	17.2* 8.0-28.5**	7.7 4.6-11.4	28.7 9.0-66.0	3.8 0.8-6.9
Et	21.5 18.8-24.1	10.0 7.8-12.2	47.9 31.8-63.9	4.7 4.1-5.3
EB	16.3 15.6-17.7	8.9 6.6-10.3	28.9 23.9-39.4	3.3 2.5-4.2
Bt1	21.6 18.1-24.5	6.5 4.2-8.9	39.1 24.6-53.0	6.1 4.6-7.4
Bt2	22.0 17.5-26.5	5.6 3.3-7.1	40.0 22.8-58.1	7.3 4.7-9.6
BC	22.5 16.9-29.3	5.7 3.4-8.1	44.3 27.8-82.2	7.8 5.0-10.2
Cca	48.5	42.0	425.3	10.1

* mean values, ** range

among the particular pedons (Table 4). The ratio of bivalent cations to monovalent cations in the Ap horizons was, on average, 17.2, and increased gradually with depth into the soils, up to 48.5 in the C horizon. A broad ratio of $Ca^{2+}+Mg^{2+}/K^{+}+Na^{+}$ is a natural feature of soils developed from loess. The ratio of cations Ca^{2+}/Mg^{2+} in the Ap horizons was, on average, 7.7, and tended to vary: it narrowed down to 5.6 in the Bt2 horizon but broadened to 42.0 in the C horizon. For plant nutrition, the ratio of 5.0-7.5 is considered to be favourable (SZYMAŃSKA et al. 2007). The average ratio of cations Ca^{2+}/K^{+} was 9-66 in the Ap horizons, 22.8-82.2 in the deeper horizons, and 425.3 in the parent rock. The value of the ratio considered to be the most suitable is 10-15 (KOPITTKE, MENZIES 2007, SZYMAŃSKA et al. 2007). The broader ratio in the Ap horions of most of the soils indicates a certain potassium deficit, resulting from insufficient application of potassium fertilisers. Due to the antagonistic effect of K^{+} towards Mg^{2+}, the ratio of magnesium cations to potassium cations is an important indicator of quality of the sorptive complex. In the Ap horizons, it was 3.8, on average, increasing deeper into the profile, thus attaining the highest value in the parent rock (10.1) – Table 4. Since the optimum value of the ratio is assumed to be 3.0 (KOPITTKE, MENZIES 2007), that indicator verifies the deficit of potassium in the Ap horizons of some of the soils under study.

Summing up the discussion, it should be highlighted that the sorptive properties of the studied Luvisols developed from loess were determined primarily by their genetic traits: content and kind of clay minerals, content of organic matter, and pH (KOPITTKE, MENZIES 2007, KAISER et al. 2008, RASHIDI et al. 2008). Clay minerals in Luvisols developed from loess are the primary sorbents. According to Uziak et al. (2004), the composition of clay minerals in loess soils is dominated by expanding mineral, mixed-packet smectite/illite, and, additionally, some illite and kaolinite, sometimes also chlorite, vermiculite or smectite. Soil humus has the higheast sorptive capabilities owing to carboxyl, hydroxyl and amine functional groups (Peinemann et al. 2000, Kaiser et al. 2008, Rashidi et al. 2008). However, Luvisols are characterised by a low content of humus, and fresh organic matter rapidly undergoes microbiological mineralization (Stojek 2005, Szymańska et al. 2007, Rychcik et al. 2008). Therefore, under the conditions of intensive cultivation with an excessive share of cereals (75% and more), regular organic fertilisation is highly important to prevent further impoverishment of the soils in TOC. Luvisols, as a result of the processes of lessivage and leaching, are often characterised by acidic reaction and migration of clayey minerals, together with base cations, downwards into the pedon. As a result of the depletion of base components by the crop yields, their supplementation is required through liming and organic fertilisation in order to satisy the needs of plants (Szymańska et al. 2007, Koćmit et al. 2008). The results of the study presented here demonstrated also that the classification of Luvisols developed from loess into various agricultural suitability complexes, based on the morphological features of pedons, affected very slightly the levels of CEC and the degree of saturation of soil sorbents with cations.

CONCLUSIONS

1. In the Ap horizons of the Luvisols developed from loess, the quantitative sequence of base cations was most frequently Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}, while in the subsurface horizons another sequence such as Ca^{2+}>Mg^{2+}>Na^{+}>K^{+} was determined The composition of base cations was dominated by calcium cations, and the content of magnesium, potassium and sodium cations was weakly diversified. TEB was favourable in the majority of the soils, and TA (content of H^{+}) was varied, but most often low.

2. CEC in the Ap, Et, EB, Bt and BC horizons of the soils was assessed to be medium or high. It was only the C horizon, containing calcium carbonate, that was characterised by very high CEC.

3. Despite the acidic or strongly acidic reaction, the degree of BS of the sorptive complex was highly favourable in most of the soils, and increased with the depth in a pedon.

4. The soils were generally characterised by favourable shares of particular cations. The percentage of calcium cations was most frequently higher than that accepted as the optimum, while the shares of magnesium and potassium cations were somewhat lower than the optimum.

5. The calculated quantitative ratios among the cations revealed big dif-

ferentiation of the values among the particular pedons. High values of the ratio of Mg^{2+}/K^{+} in the Ap horizons of most of the soils indicated a slight deficit of potassium resulting from the application of small doses of potassium fertilisers.

6. The content of cations Mg^{2+}, TEB and CEC in the Ap horizons of soils from the very good wheat complex were lower than in the Ap horizons of soils from the good wheat complex and the deficient wheat complex. However, the differences in the content of Ca^{2+}, K^{+}, Na^{+} and H^{+} and in the BS among soils classified in the different soil sutability complexes were very small.

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