DE GRUYTER
OPEN

DOI: 10.1515/ssa-2015-0008

SOIL SCIENCE ANNUAL
Vol. 65 No. 4/2014: 150–155

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Contribution of granulometric fractions in phosphorus distribution in old alluvial soil

Abstract: Phosphorus content and balance in granulometric fractions of old alluvial soil developed from alluvial deposits od Vistula River in middle Poland was studied. The distribution of phosphorus in particular granulometric fractions of the studied soil showed high quantitative variability vertically in the profile. This resulted from the layered structure of the Vistulian old alluvial formation developed throughout the Holocene. The contribution of grain fractions in phosphorus accumulation increased with a decrease in their diameter, and in certain fractions with a decrease in their quantitative state. Eluviation of phosphorus down the soil profile concerned in particular grain fraction <0.02 mm. Fractions with a larger diameters were not subject to the process. Phosphorus resources calculated from the grain fraction balance in the analysed soil amounted to an average of 1.7 kg·m^2 to a depth of 200 cm.

Key words: phosphorus, fractions, granulometric composition, balance, old alluvial soil

INTRODUCTION

Phosphorus is one of the key elements in living organisms. It serves as an energy carrier in complex organic compounds in plants, animals, and humans. Its resources on Earth are limited, similarly as those of the majority of fossil fuels. According to calculations by geologists, phosphorus resources on Earth amount to 16 billion tonnes (Bondre 2011). Moreover, dispersed deposits with very low concentration of phosphorus are recorded, amounting to 35 billion tonnes. Considering the scale of the current demand, the resources are estimated to last for the next 150 to 175 years.

Considering these data, it is worth studying how to balance phosphorus resources in soils. Polish research regarding the content of phosphorus in soils has been conducted for many years (e.g. Moskal 1963; Brogowski 1966; Brogowski and Okołowicz 1986; Borowiec 1988; Pokojska 1979; Czępińska-Kamińska 1994; Oktaba and Czerwiński 2003; Szara et al. 2005; Sapek 2007). The works, however, do not discuss the balance of phosphorus resources in particular types of soils.

This paper attempts to determine the phosphorus content and balance in particular granulometric fractions. The determination of phosphorus resources in fractions of various soil formations may permit the calculation of its approximate resources in soils exclusively based on the grain size composition, similarly as grain size composition can provide the basis for the calculation of certain physical properties of soils (Brogowski 1990).

MATERIALS AND METHODS

Endoeutric Cambisol was sampled at the outskirts of the Kampinoska Forest in the vicinity of Kazuń Polski village on the old terrace of the Vistula River. The analysed soil in the oxbow lake was composed of layered sediments of the Vistula River, probably from the period of late Pleistocene (particularly the deeper layers).

The soil was separated into granulometric fractions in 5 litre glass bottles after boiling without chemical peptization in order not to modify the chemical composition of fractions. After boiling, the soil was stirred with a rotary stirrer, and transferred to the bottles. The clay fraction was fully separated by means of multiple repetitions of the boiling and stirring process. Fractions with a larger diameter were separated with no further boiling. They were only stirred with a rotary stirrer for approximately a dozen minutes. Water after the deposition of the separated fraction was siphoned off, and used for further separation of fractions. Grains with a diameter of 1.0–0.1 mm were dried and sieved.

The bulk density of particular granulometric fractions was determined by bulk method in four repetitions. The density was used for the calculation of phosphorus balance in the fractions.

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The soil reaction was determined potentiometrically in H_2O and 1 mol·dm^3 KCl. The organic carbon was analysed by means of an automatic carbon analyser by Shimadzu TOC 5000A, and phosphorus by molibdenian method in which p-methylaminophenol sulphate (metol) was used for reduction instead of tin chloride. The method eliminates the potential presence of silica in the solution, giving the same colour as phosphorus. Moreover, the colour of the phosphate solution caused by this method is permanent, and is maintained even for several months (Brogowski 1966).

RESULTS

The content of phosphorus in particular granulometric fractions (Table 1) of the analysed soil increased with a decrease in their diameter (Table 2).

Fraction with a diameter <0.002 mm constituted an average of 15.5% of whole soil in the uppermost part of the profile composed of old alluvial formations to a depth of 150 cm. Below, to a depth of 200 cm of whole soil constituting alluvial sediments, its contribution amounted to only 4.1% (Table 1). The content of phosphorus in the fraction <0.002 mm evidently corresponds with the character of old alluvial sediments (Table 1 and 2). In the uppermost part of the profile, to a depth of 70 cm, the fraction is of 50% poorer in phosphorus than the same fraction from horizons at a depth of 70–150 cm, and by as much as 142% in comparison to horizons below 150 cm. This suggests increasing content of phosphorus compounds in whole soil with a decrease of the content of fraction (Table 1, 2, and 4). In horizons to a depth of 70 cm, the fraction is depleted in phosphorus compounds most likely as a result of the leaching process.

Fraction <0.002 mm accounts for the accumulation of an average of 43.6% of total phosphorus occurring in the soil in the analysed profile. The values in particular genetic horizons vary considerable from 29.6% in A horizon to 54.7% in the deepest horizons underlying the old alluvial formation (Table 3). Based on the calculation of phosphorus balance in the profile, the fraction <0.002 mm accumulates 1.08 kg of this element in the analysed soil with an area of 1 m^2 to a depth of 200 cm.

Fraction with a diameter of 0.005–0.002 mm reached an inconsiderable quantitative contribution in the whole soil, averaging 2.3% in the profile, varying from 0.6% in the deepest horizon to 4.1% in the uppermost part of the profile (Table 1). In contrast to fraction <0.002 mm, the fraction 0.005–0.002 mm showed

TABLE 1. Texture of soil, its pH, and content of humus.

Depth (cm)	Genetic horizons	Percentage of fraction, grain size in mm								pH		Content of humus
		1.0–0.25[1]	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.01	0.01–0.005	0.005–0.002	<0.002	H_2O	KCl	
0–30	Ap	8.2	33.2	13.2	17.9	6.7	4.3	3.5	13.0	5.0	4.0	1.20
30–50	ABw	7.5	34.9	13.3	18.9	6.5	3.0	3.5	12.4	5.4	4.1	0.48
50–70	Bw	4.2	27.7	13.0	15.6	6.2	3.4	4.1	25.8	5.6	4.1	0.33
70–90	C	1.2	30.6	34.8	11.6	2.1	2.3	1.6	15.8	5.7	4.2	0.34
90–120	2C	2.9	48.6	14.6	14.4	2.8	1.7	1.4	13.6	5.7	4.2	0.21
120–150	3C	5.3	40.0	16.3	18.4	3.0	1.9	2.4	12.7	5.6	4.3	0.16
150–175	4D	20.5	46.4	11.0	6.7	10.0	0.6	1.0	3.8	6.4	5.5	0.05
175–200	5D	26.3	52.7	10.2	4.6	0.8	0.4	0.6	4.4	6.9	6.1	0.03
Average		9.5	39.3	15.7	13.5	4.8	2.2	2.3	12.7	–	–	

[1] Grains with a diameter of 1–0.5 mm occurred in the soil only in trace amounts, below 1%.

TABLE 2. Total content of phosphorus (H_2PO_4) in fractions in mg per 100 g

Depth (cm)	Genetic horizons	Content of phosphorus in mg per 100 g; grain size in mm								Average for the genetic horizons
		1.0–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.01	0.01–0.005	0.005–0.002	<0.002	
5–30	Ap	17.5	20.0	27.5	32.5	72.5	117.5	290.0	242.5	70.0
30–50	ABw	7.5	17.5	22.7	30.0	45.0	80.0	140.0	275.0	59.5
50–70	Bw	15.0	17.5	20.0	25.0	40.0	90.0	132.0	277.5	94.5
70–90	C	18.4	20.0	20.0	24.4	70.0	145.2	275.3	345.0	79.8
90–120	2C	16.1	12.5	16.5	25.0	70.6	148.5	218.4	408.0	75.6
120–150	3C	17.5	12.7	20.0	30.0	87.5	190.0	280.0	425.0	79.3
150–175	4D	5.0	7.5	35.0	62.5	82.1	121.4	232.5	660.0	46.7
175–200	5D	8.5	5.0	20.0	55.0	116.5	162.5	215.6	645.0	40.7
Total		105.5	112.7	181.7	284.4	584.2	1055.1	1783.8	3278.0	546.1
Average		13.2	14.1	22.7	35.6	73.0	131.9	223.0	409.8	68.3

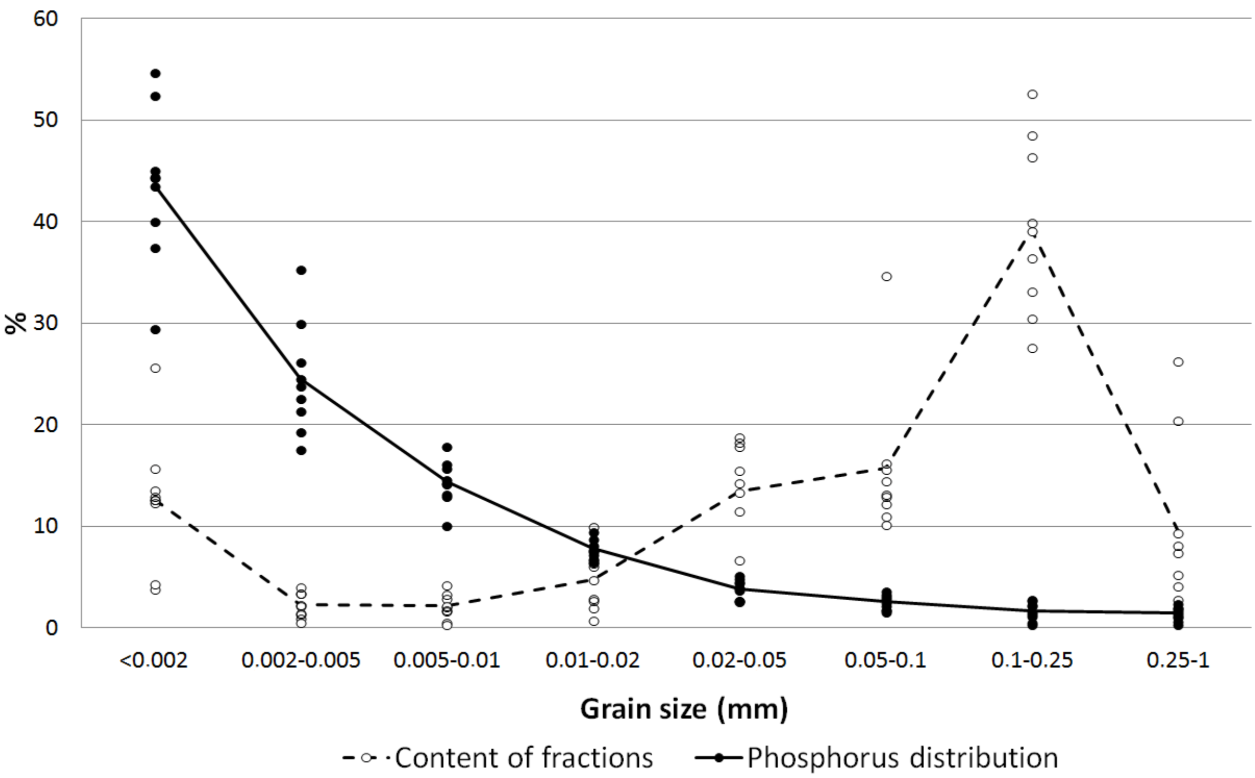

FIGURE. Per cent content of grain fractions, and phosphorus distribution in the fractions

a relatively even content of phosphorus in particular genetic horizons of the soil profile (Table 2 and Figure). The contribution of the fraction in the accumulation of total phosphorus in the analysed soil averaged 24.6%, varying in particular horizons from 17.6% to 35.4%. The discussed fraction is poorer in phosphorus in comparison to fraction <0.002 mm by an average of 45.6%. Therefore, a considerable difference in the content of phosphorus is observed between grains with similar dimensions (Table 2 and 3). According to the balance, low content of the 0.005–0.002 mm fraction (Table 1) accounts for 94.3 g H_2PO_4 in the profile with an area of 1 m^2 to a depth of 200 cm, varying in particular horizons and layers of alluvial sediments from 2.4 to 25.3 $g{\cdot}m^{-2}$ (Table 5).

Fraction with a diameter of 0.005–0.01 mm reached an inconsiderable contribution in the whole soil, similarly as the fraction discussed above. Its mean content in the soil amounted to 2.2%, with values varying in particular genetic horizons of the soil profile from 0.4% in the deepest horizon to 4.3% in the A horizon (Table 1). The discussed fraction is poorer in phosphorus than the fraction with a diameter 0.005–0.002 mm by an average of 40.8%, and than fraction <0.002 mm by 67.8%. The distribution of phosphorus in this fraction in the soil profile is variable (Table 2). The lowest amount of phosphorus bound to this fraction occurred in the uppermost part of the profile, and the highest in the middle part. The per cent contribution of the fraction in phosphorus accumulation is very even throughout the profile (Table 3 and Figure). This fraction accounted for an average of 14.4% of total phosphorus accumulated in the analysed soil, with values varying in particular genetic horizons from 10.1 to 17.9%. Due to the low content of the discussed fraction in whole analysed soil (Table 1), only 55.9 g $P{\cdot}m^{-2}$ on average was accumulated to a depth of 200 cm (Table 5).

Fraction with a diameter of 0.01–0.02 mm had an average contribution of 4.8% in whole soil, varying in the profile from 0.8 to 10.0% (Table 1). In comparison to the clay fraction (<0.002 mm), this fraction is poorer in phosphorus compounds by an average of 82.2%. The content of phosphorus in the fraction 0.01–0.02 mm increased gradually down the soil profile, excluding horizon A (Table 2). The deepest horizon (175–200 cm) with the lowest content of the fraction is the most abundant in phosphorus (Table 1). The per cent contribution of the fraction in phosphorus accumulation is very low, accounting for binding of only 7.8% on average of total phosphorus in the soil (Table 3 and Figure). The contribution of the fraction in binding phosphorus is similar to its per cent contents in the whole analysed soil (Figure).

A quantitative increase in the fraction 0.01–0.02 mm in relation to the one discussed above resulted in an

TABLE 3. Contribution of granulometric fractions in phosphorus accumulation in soil (in %).

Depth (cm)	Genetic horizons	Grain size in mm[1]						
		1.0–0.25	0.1–0.02	0.02–0.01	0.01–0.005	0.005–0.002	<0.002	<0.02
5–30	Ap	4.5	7.4	8.8	14.3	35.4	29.6	88.1
30–50	ABw	4.0	8.6	7.3	13.0	22.7	44.4	87.4
50–70	Bw	5.2	7.2	6.5	14.6	21.4	45.1	87.2
70–90	C	2.2	4.9	7.6	15.8	30.0	37.5	90.9
90–120	2C	3.2	4.5	7.7	16.2	23.9	44.5	92.3
120–150	3C	2.8	4.7	8.2	17.9	26.3	40.1	92.5
150–175	4D	1.0	8.1	6.8	10.1	19.3	54.7	90.9
175–200	5D	1.1	6.1	9.5	13.2	17.6	52.5	92.8
Average		3.2	6.4	7.8	14.4	24.6	43.6	90.4

[1] Total phosphorus (mg per 100 g) in genetic horizons in fractions <1 mm = 100%.

TABLE 4. Per cent contribution of genetic soil horizons in phosphorus accumulation by particular granulometric fractions. Total phosphorus in a particular fraction in the soil profile at a depth from 0 to 200 cm = 100% (see Table 2)

Depth (cm)	Genetic horizons	Grain size in mm[1]							
		1.0–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.01	0.01–0.005	0.005–0.002	<0.002
5–30	Ap	16.6	17.7	15.1	11.4	12.4	11.1	16.3	7.4
30–50	ABw	7.1	15.5	12.5	10.5	7.7	7.6	7.8	8.4
50–70	Bw	14.2	15.5	11.0	8.8	6.8	8.5	7.4	8.5
70–90	C	17.4	17.7	11.0	8.6	12.0	13.8	15.4	10.5
90–120	2C	15.3	11.1	9.1	8.8	12.1	14.1	12.2	12.4
120–150	3C	16.6	11.3	11.0	10.5	15.0	18.0	15.7	13.0
150–175	4D	4.7	6.6	19.3	22.0	14.0	11.5	13.0	20.1
175–200	5D	8.1	4.6	11.0	19.4	20.0	15.4	12.2	19.7
Average		100%	100%	100%	100%	100%	100%	100%	100%

increase in the amount of the accumulated phosphorus. It amounts to an average of 70.2 g P per 1 m^2 to a depth of 200 cm (Table 5). The variations in the value in the profile are proportional to the content of granulometric fractions (Table 1 and 5).

Fractions with a diameter of 0.02–0.1 mm reached a considerable contribution in whole soil, averaging 21.2% in the profile (Table 1). The fractions are poorer in phosphorus by 93.0% than the richest fraction (<0.002 mm). Therefore, their contribution in the total content of phosphorus amounted to approximately 7.0% (Tables 2 and 3, Figure). The distribution of phosphorus in the fractions in the soil profile is relatively even with the exception of the fraction with a diameter of 0.05–0.02 mm, largely enriched in phosphorus in the deepest horizons (Table 2). Fractions 0.02–0.01 mm combined accumulated an average of 212.6 g P per 1 m^2 in the analysed soil to a depth of 200 cm (Table 5). This relatively high amount of accumulated phosphorus results from a high contribution of the fractions in the soil mass (Table 1 and 3).

Fraction with a diameter of 0.1–1.0 mm constituted almost half of whole soil, and amounted to a total of 48.7% (Table 1). The fraction contained low amounts of phosphorus amounting to an average of 3.5% of the total resources in the analysed soil (Table 2 and 3, Figure). The fraction binds only 188 g of phosphorus in the analysed soil per 1 m^2 of the profile to a depth of 200 cm (Table 5).

TABLE 5. Phosphorus balance in grain fractions of soil in $g \cdot m^{-2}$ of genetic horizons

Depth (cm)	Genetic horizons	Grain size (mm)								
		1.0–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.01	0.01–0.005	0.005–0.002	<0.002	sum
5–30	Ap	5.0	27.4	13.3	19.9	13.6	13.3	25.2	75.7	193.4
30–50	ABw	1.4	20.4	8.4	16.0	7.0	5.0	9.9	76.6	144.7
50–70	Bw	1.7	15.0	7.5	10.9	5.8	6.4	10.8	183.2	241.3
70–90	C	0.6	18.5	20.9	7.9	3.3	7.1	11.6	153.5	223.4
90–120	2C	2.1	28.8	10.4	14.4	6.5	8.2	9.2	190.4	284.4
120–150	3C	4.4	24.4	14.8	23.0	8.8	12.0	19.6	213.8	320.8
150–175	4D	4.1	14.2	14.4	14.4	22.6	2.1	5.6	75.5	152.9
175–200	5D	9.3	10.7	7.6	8.8	2.6	1.8	2.4	93.5	136.7
Total		28.6	159.4	97.3	115.3	70.2	55.9	94.3	1076.6	1697.6

DISCUSSION

Phosphorus is an element which compounds considerably respond to the soil-forming processes occurring in the soil profile (Pokojska 1979; Czępińska-Kamińska 1994). Therefore, the calculated per cent contribution of genetic horizons of the analysed soil in phosphorus accumulation by particular granulometric fractions clearly identifies those susceptible to the leaching processes, and those resistant to the process (Table 4 and Figure).

Grains with a diameter of >0.05 mm show no vertical migration of phosphorus compounds in the profile of the analysed soil. This may result from the fact that grains with such a diameter are not enriched in phosphorus compounds, and their low amounts may occur in the grains in the form of inclusions in mineral grains. Grains with diameters of <0.05 mm show evident deficits of phosphorus in the horizons of the analysed soil to a depth of 70, and even 120 cm (Table 4). At the highest depths, phosphorus is removed from grains with a diameter of 0.05–0.02 mm. The grains <0.02 mm, including clay fraction <0.002 mm, show evident deficits of phosphorus to a depth of 70 cm (Table 4).

Granulometric fractions with a diameter of 0.05–0.002 mm from the uppermost horizon to a depth of 30 cm are enriched in phosphorus in relation to the fractions from horizons 30–70 cm. This may result from the presence in the fractions of organic compounds containing phosphorus but still not fully humified. Therefore, the leaching processes are not capable of removing phosphorus from organic compounds (Table 4). Clay fraction <0.002 mm shows evident depletion in phosphorus compounds in horizon Ap. In this fraction, organic compounds are usually fully humified, and phosphates could be subject to leaching during the process (Table 4), together with fulvic acids soluble in water.

CONCLUSIONS

1. The content of phosphorus in granulometric fractions increased more or less evenly with a decrease in their diameter.
2. The accumulation of phosphorus in certain cases increased in the same group of fractions with a decrease in its quantitative state in the soil mass.
3. The main phosphorus resources in the analysed soil are accumulated in granulometric fractions with a diameter of <0.02 mm. They accumulate an average of 90.4% of total phosphorus occurring in the soil. The values in particular horizons and layers vary from 87.2 to 92.8%.
4. The distribution of phosphorus among particular granulometric fractions in genetic horizons of the soil profile may constitute an indicator of soil-forming processes.
5. Leaching processes in the analysed soil concerned all fractions with a diameter of <0.02 mm, and particularly the fraction with a diameter of <0.002 mm.
6. Based on the calculated phosphorus balance in the analysed soil, the resources of this element per 1 m^2 to a depth of 200 cm amount to approximately 1.7 kg, and to a depth of 1 m – 0.8 kg.

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Received: December 15, 2014
Accepted: February 18, 2015

Udział frakcji granulometrycznych w rozmieszczeniu fosforu w glebie staroaluwialnej

Streszczenie: Badano zawartość oraz obliczono bilans fosforu we frakcjach granulometrycznych wydzielonych z gleby staroaluwialnej, wytworzonej z osadów rzecznych Wisły w środkowej Polsce. Zawartość fosforu w poszczególnych frakcjach granulometrycznych badanej gleby wykazuje duże zróżnicowanie ilościowe w pionie profilu. Wynika to z warstwowej budowy utworu staroaluwialnego Wisły powstałego na przestrzeni całego okresu holoceńskiego. Udział frakcji w magazynowaniu fosforu wzrasta wraz ze zmniejszaniem się ich średnicy oraz w niektórych frakcjach wraz ze zmniejszaniem się ich stanu ilościowego. Wymywanie fosforu w głąb profilu glebowego dotyczy głównie frakcji <0,02 mm. Frakcje o większej średnicy nie są objęte tym procesem. Zasoby fosforu obliczone z bilansu frakcji w badanej glebie wynoszą średnio 1,7 kg na m^2 do głębokości 200 cm.

Słowa kluczowe: fosfor, frakcje, skład granulometryczny, bilans, gleba staroaluwialna