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An attempt of using soil grain size in calculating the capacity of water unavailable to plants

Abstract: The aim of this research was to finding methods of calculating the content of water unavailable to plants in the total soil mass based on the water properties of particular grain sizes. Fractions <0.02 mm bind from 90.1 to 98.8% of total water unavailable to plants in soils, and the clay fraction (<0.002 mm) alone binds from 52.1 to 80.1% of this water. Binding water in fractions <0.02 mm significantly depends on the mineralogical composition of fractions. The presence of illite, chlorite or kaolinite causes a decrease of capacity of water unavailable to plants by even 40% in relation to fractions composed of smectites, vermiculites, and humus. Due to high variability of the capacity of water unavailable to plants in particular grain size fractions <0.02 mm resulting from the variable mineralogical composition of this fraction, coefficients allowing to calculate the capacity of water unavailable to plants in soil microcapillaries below 0.2 μm show very high oscillation and could not be applicable.

Keywords: water unavailable to plant, soil grain size, clay minerals

INTRODUCTION

Water is one of the basic components of soil. Its function has many aspects, because it takes part in the chemical, physical and biological processes in soils. Part of soil water bound by the pF forces exceeding 4.2 is unavailable to plants. This water occurs in capillaries below 0.2 μm in diameter.

Quantitative determination of particular soil water types bound by various forces is a difficult and arduous task. In the past, Trzecki (1968, 1974, 1976) made attempts of finding methods of calculating their content in the total soil mass based on the water properties of particular grain sizes. The obtained results were satisfactory, but the studies were focused only on two soil types and only on their arable-humus horizons.

Based on the studies by Trzecki (1968, 1974, 1976), an attempt was undertaken to analyze complete soil profiles (down to 150 cm) developed from parent rocks of variable geological origin. The study was focused entirely on the quantitative binding of water unavailable to plants in all distinguished grain size fractions. Earlier studies of the mineralogical composition of the fraction <0.02 mm (Brogowski et al. 1978, 1983; Brogowski and Mazurek 1981, 1986, 1990; Tyler and Wheateraft 1992; Lipiec and Stępniewski 1995; Pranagal et al. 2005), as well as studies on the binding of water in soil and its grain size fractions (Waksmundzki et al. 1981, Raczuk 1987; Rieu and Sposito 1991; Comegna et al. 1998; Witkowska-Walczak et al. 2003) were also applied in the analysis.

MATERIAL AND METHODS

Samples for studies were collected from the basic genetic soil horizons. Soil samples (0.5 kg) were elutriated in 5 liter containers. The samples were boiled and mixed with a rotary agitator to remove the clay fraction <0.002 mm. Boiling and mixing was repeated to the moment when the clay fraction was completely removed from the soil. The suspension with the clay fraction was evaporated in a water bath, dried at 105°C and weighed; next, its content was calculated. Fractions of larger size (0.002–0.1 mm) were separated without boiling, but by mixing with an electric rotary agitator. Sand grains after separating grains smaller than 0.1 mm were dried and separated on sieves. After separation and calculation of the grain size composition, the particle and bulk density was determined. The densities were used to calculate total porosity; bulk density was used to calculate the weight of particular fractions in 1 m^2 of the genetic horizons. Bulk density was determined by filling volumetric glass cylinder by oven dry soil fractions and cylinder with soil fraction was knock several times until the fraction in cylinder

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was not more settle down. Then cylinder with soil fractions was weighted, the weight of empty cylinder was subtracted, and the bulk density was calculated. Determination was made in four repetitions.

Particle density was determined using the picnometer method in 2 repetitions. Maximal hygroscopy was determined using the Nikolajev method in two repetitions. Water unavailable to plants was calculated by multiplying maximal hygroscopy – MH by 1.7, following Musierowicz and Król (1962) method.

RESULTS

Brief characteristic of the soils

Three soil profiles with similar genetic processes but different geological origin of the soil substrate were selected for the analysis.

Profile 1 (Gąbin) was developed from glacial till of the Middle Polish Glaciations (Riss) and was nonuniform. Ap and Bw horizons are composed of light glacial till lying on red till with prismatic structure. Probably, the tills represent two different generations in the studied profile. This fact is evidenced by binding of unavailable water in the clay fraction (Table 1–3). This soil is a leached brown soil (Cambisol). The mineralogical composition of the <0.02 mm fraction is completely different in comparison to the other soils studied. The fraction is dominated by illite, chlorite and mixed-layer illite-smectite complexes in the <0.002 mm fraction. Significant amounts of quartz and feldspars occur in fractions 0.02–0.002 mm (Brogowski and Mazurek 1990). Clay minerals occurring in the soils – illite and chlorite – do not show significant affinity to water in comparison to smectites.

Profile 2 (Wilanów) was composed of Holocene alluvial deposits of the Vistula River, showing horizontal stratification down to 200–240 cm. The grain size composition is dominated by silt (0.1–0.02 mm), followed by sand (1–0.1 mm) and clay (<0.002 mm) (Table 1). The bottom is underlined by the sand. The remaining fractions do not show significant differences in their content within the soil profile. The soil was assigned to brown alluvial soil (Fluvisol with cambic properties). The mineralogical composition of the clay fraction (<0.02 mm) (Brogowski and Mazurek 1986) is similar to that of the old alluvial soil from Kazuń, although the crystalline structure of the clay minerals is less distinct.

Profile 3 (Kazuń Polski) localized in an old alluvial terraces was composed of horizontally stratified deposits of the Vistula River, probably from the terminal part of the Pleistocene. The soil was composed of alluvial deposits, however it exhibited the features of Cambisol rather than Fluvisol. The dominating fraction is sand (1–0.1 mm), followed by silt (0.1–0.02 mm) and clay (<0.002 mm). The 0.02–0.002 mm fraction has the lowest content in the soil mass (Table 1). The mineralogical composition of the fraction <0.02 mm is dominated by illite with significant admixture of smectite in the fraction <0.002 mm (Brogowski and Mazurek 1981). In the coarser fractions illite prevails with trace quantities of kaolinite and quartz. In horizons down to 50 cm the clay fraction showed some amounts of zeolites from the phillipsite and chabazite group (Brogowski et al. 1978, 1979, 1983).

Water unavailable to plants in the grain size fractions of soils

This type of water fills soil capillaries below 0.2 μm in diameter (pF = <4.2), thus its content depends not only on the soil grains diameter but also on the mineralogical composition of the fraction and humus content. In some clay minerals (i.e. in montmorillonite), water molecules in the diameter of 2.74Å(Å=10^{-8} mm) may be bound in the interlayer space. Due to this fact, the content of unavailable water bound in grains of the same size may vary depending on the character of the mineral. Thus, the idea of Trzecki (1968, 1974, 1976) may not have practical application in calculating the quantity of water types bound by particular soil fractions.

Grains 1–0.1 mm in diameter bind trace quantities (0.2–3.1%) of water unavailable to plants (Table 2). Oscillations of the values depend on the geological origin of the soil material and the genetic horizons. Grains of this type from soil of the old accumulation terrace (Profile 3) bind 2.7 to 2.8 times more water unavailable to plants than grains from the alluvial soil (Profile 2) and the soil developed from glacial till (Profile 1). Higher amounts of unavailable water in Profile 3 results from some quantities of minerals from the zeolite group – chabazite and phillipsite, which may occur in grains of different diameter (Brogowski et al. 1983). These minerals bind high amounts of water.

The share of sand grains (1–0.1 mm) in non available water binding in relation to its sum bound by all fractions equal – 100% in the studied soils varies averagely from 0.2 to 5.4% between the soil profiles. The fraction 1–0.1 mm, apart of its diameter and mineralogical composition (mainly quartz and some amounts of feldspars) may bind from 2.36 to 6.8 kg H_2O per 1 m^2 of the soil profiles down to 150 cm (Table 5). The highest content of this water is bound by the sand fraction from soil of the old accumulation terrace (Profile 3) containing some amounts of minerals from the zeolite group.

TABLE 1. Grain size composition of soils

Locality	Horizon	Depth in cm	Percent of grains in diameter in mm									
			1–0.5	0.5–0.25	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	Σ <0.02
Profile1	Ap	0–25	5.7	14.7	35.6	15.4	8.6	4.3	4.3	4.2	7.2	20.0
(Gąbin),	Bw	25–50	4.4	11.8	29.6	18.5	7.5	5.6	5.5	6.2	10.5	27.8
Gostynin	Bw/C	50–75	1.5	2.7	19.2	14.8	6.7	5.5	7.3	9.4	32.9	55.1
county	C	75–100	1.3	4.6	16.8	13.7	6.0	7.0	7.7	0.1	33.8	57.6
	2C	100–125	1.6	4.8	9.5	21.8	3.6	6.4	8.3	10.8	33.2	58.7
	3C	125–150	1.8	5.2	14.6	13.3	6.9	8.8	8.6	8.0	32.8	58.2
Averge		0–150	2.7	7.3	20.9	16.2	6.6	6.3	7.0	7.9	25.1	46.3
Profile 2	Ap	0–30	0.0	6.0	20.3	22.6	20.2	7.5	8.4	5.0	10.0	30.9
(Wilanów)	Bw	30–60	0.0	0.2	6.8	19.0	35.0	10.4	1.4	7.8	19.4	39.0
Warsaw city	Bw/C	60–90	0.0	2.5	21.3	12.0	36.3	6.5	4.1	4.5	12.8	27.8
	CG1	90–120	0.0	1.3	6.7	14.5	40.3	11.4	6.2	4.1	15.5	37.2
	CG2	120–150	0.9	0.0	21.6	15.5	29.6	10.0	3.1	2.8	16.5	32.4
Average		0–150	0.0	2.0	15.5	16.7	32.3	9.2	4.6	4.8	14.9	33.7
Profile 3	Ap	0–25	1.1	7.1	33.2	13.2	17.9	6.7	4.3	3.5	13.0	27.5
(Kazuń Polski)	Bw	25–50	1.2	6.3	34.9	13.3	18.9	6.5	3.0	3.5	12.4	25.4
Modlin county	Bw/C	50–75	0.4	3.8	27.7	13.0	15.6	6.2	3.4	4.1	25.8	39.5
	C	75–100	0.2	1.0	30.6	34.8	11.6	2.1	2.3	1.6	15.8	21.8
	2C	100–125	0.1	2.7	48.6	14.6	14.4	2.8	1.7	1.4	13.6	19.5
	3C	125–150	0.3	5.0	40.0	16.3	18.4	3.0	1.9	2.4	12.7	20.0
Average		0–150	0.5	4.3	35.8	17.5	16.1	4.5	2.8	2.7	15.6	25.6

TABLE 2. Capacity of water unavailable to plants in the grain size fractions of soils in percents

Locality	Horizon	Depth in cm	Percent of grains in diameter in mm									
			1–0.5	0.5–0.25	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 = 100%*
Profile1	Ap	0–25	0.90	0.44	0.17	0.68	2.04	2.30	3.33	8.63	51.20	70.39
(Gąbin),	Bw	25–50	0.34	0.30	0.20	0.36	0.73	1.65	1.22	7.14	45.90	57.84
Gostynin	Bw/C	50–75	0.39	0.22	0.19	0.20	0.82	1.00	1.14	6.24	34.00	44.20
county	C	75–100	0.24	0.24	0.19	0.17	0.34	0.71	0.95	3.48	26.26	32.58
	2C	100–125	0.22	0.20	0.17	0.31	0.61	0.90	1.75	2.98	23.80	30.94
	3C	125–150	0.39	0.19	0.17	0.22	0.36	1.04	1.56	3.16	27.30	34.39
Averge		0–150	0.41	0.26	0.18	0.32	0.82	1.27	1.66	5.27	34.74	45.00
Profile 2	Ap	0–30	lack	0.06	0.20	0.29	0.42	5.32	3.84	14.45	57.63	82.21
(Wilanów)	Bw	30–60	of this	0.02	0.19	0.22	0.88	5.64	7.72	17.65	51.68	84.00
Warsaw city	Bw/C	60–90	fraction	0.24	0.24	0.34	0.51	6.63	4.27	11.53	36.30	60.06
	CG1	90–120		0.41	0.46	0.26	0.41	1.92	3.70	10.10	37.86	55.12
	CG2	120–150		0.08	0.78	0.60	2.21	2.62	4.69	6.14	47.85	64.97
Average		0–150		0.16	0.37	0.34	0.88	4.43	4.84	11.97	46.26	69.27
Profile 3	Ap	0–25	0.80	0.75	0.29	1.00	2.65	4.67	10.00	18.56	97.48	136.20
(Kazuń Polski)	Bw	25–50	0.61	1.73	0.54	0.46	0.85	2.45	4.47	16.40	78.64	106.45
Modlin county	Bw/C	50–75	0.48	1.65	0.49	0.54	1.46	3.93	4.66	10.83	43.25	67.29
	C	75–100	0.63	1.94	0.54	0.51	2.07	6.20	6.66	8.79	29.60	56.44
	2C	100–125	0.82	0.82	0.29	0.41	0.73	2.16	4.69	7.27	28.47	45.66
	3C	125–150	0.61	0.61	0.39	0.60	1.63	2.80	4.00	9.04	37.84	57.52
Average		0–150	0.66	1.25	0.42	0.58	1.56	3.70	5.75	11.81	52.55	78.30

* Sum was assumed as 100%; the percentage share of particular grain size of soil in binding of water unavailable to plants were calculated (Table 3).

Grains 0.1–0.02 mm in diameter occurring in the studied soils bind about 1.2 to 2.5 time more water unavailable to plants than the sand fraction (1–0.1 mm) (Table 1 and 2). Oscillations of the contents of this water type in particular genetic horizons of the studied soils are significant, with often multiple differences (Table 2). In turn, their contribution in the accumulation of water unavailable to plants in relation to its content in all fractions assumed as 100% does not vary significantly from the content of sand grains (1–0.1 mm) (Table 3). Oscillations in the genetic horizons vary from 0.9 to 4.5%. Similarly, the content of this water type per 1m^2 of soil surface down to 150 cm in the profiles varies from 2.74 to 7.62 kg. Larger amounts of water unavailable to plants are accumulated by the silt fractions (0.1–0.02 mm) of alluvial soil (Profile 2) due to their domination in the soil (Table 1 and 5).

Grains 0.02–0.01 mm in diameter are not abundant in the studied soils, reaching 4.5 to 9.2% in the soil profiles on average (Table 1). They bind also small quantities of water unavailable to plants (Table 2). Oscillations in the genetic horizons of the soil profiles reach from 0.71 to 6.63%. The richest fractions in this water type were noted in Profile 2 (Wilanów). The contribution of this fraction in the water balance of all fractions is also low and varies from 2.2 to 11.0% within the genetic horizons (Table 3). The lowest content of water unavailable to plants was noted in the studied fraction (0.02–0.01 mm) in soil developed from heavy glacial till (Table 2 and 3). This is determined by the mineralogical composition of this fraction (Brogowski and Mazurek 1990), which is dominated by quartz, illite, and kaolinite, and also chlorite in the deeper horizons, thus minerals with low hydration properties.

Due to its low content in the soil mass (Table 1), the fraction 0.02–0.01 mm is responsible for the accumulation of 1.36 kg of water in soil developed from glacial till (Gąbin) to 6.74 kg in alluvial soil (Wilanów) containing slightly higher amounts of this fraction per 1 m^2 of soil to the depth of 150 cm (Table 1 and 5).

Grains 0.01–0.005 mm in diameter represent averagely 2.7 to 7.0% in the studied profiles, with oscillations from 1.4 to 8.6% in the genetic horizons (Table 1). They bind slightly larger amounts of water unavailable to plants in comparison to the previous fractions (Table 2). The fraction 0.01–0.005 mm separated from soils developed on old or present-day alluvial deposits (Profile 2 and 3) are from 2.9 to 3.5 times richer in water unavailable to plants in comparison to fractions separated from glacial till (Profile 1). In this case, significant influence of the mineralogical composition of the studied fraction on the possibilities of binding water unavailable to plants can be observed (Brogowski et al. 1978; Brogowski and Mazurek 1981, 1986, 1990).

The percentage content of the fraction 0.01–0.005 mm in the accumulation of water unavailable to plants in relation to all fractions varies from 3.8% in soil developed from glacial till (Profile 1) to 7.9% in soil

TABLE 3. Percentage share of the separate grain size of soil in binding water unavailable to plants (the sum of water in all granulometric fractions in soil horizons = 100%, Table 2)

Locality	Horizon	Depth in cm	Soil grains in diameter in mm						
			1–0.1	0.1–0.02	0.02–0.01	0.01–0.005	0.005–0.002	<0.002	Σ<0.02
Profile1	Ap	0–25	2.1	3.9	3.3	4.7	12.4	73.6	94.0
(Gąbin),	Bw	25–50	1.4	1.9	2.8	2.1	12.3	79.5	96.7
Gostynin	Bw/C	50–75	1.8	2.3	2.3	2.6	14.1	76.9	95.9
county	C	75–100	2.0	1.5	2.2	2.9	10.7	80.7	96.5
	2C	100–125	1.8	3.0	2.9	5.7	9.6	77.0	95.2
	3C	125–150	2.2	1.7	3.0	4.5	9.2	79.4	96.1
Averge		0–150	1.9	2.4	2.8	3.8	11.4	77.7	95.6
Profile 2	Ap	0–30	0.3	0.9	6.5	4.7	17.6	70.0	98.8
(Wilanów)	Bw	30–60	0.2	1.3	6.7	9.2	21.0	61.6	98.5
Warsaw city	Bw/C	60–90	0.8	1.4	11.0	7.1	19.2	60.5	97.8
	CG1	90–120	1.5	1.2	3.5	6.7	18.3	68.8	97.3
	CG2	120–150	1.3	4.3	3.4	7.2	9.5	73.7	93.8
Average		0–150	0.8	1.8	6.2	7.0	17.1	67.1	97.4
Profile 3	Ap	0–25	1.4	2.6	3.4	7.3	1.36	71.7	96.0
(Kazuń Polski)	Bw	25–50	2.7	1.2	2.3	4.2	15.40	74.2	96.1
Modlin county	Bw/C	50–75	3.8	3.0	5.8	6.9	16.10	64.4	93.2
	C	75–100	5.4	4.5	10.9	11.7	15.40	52.1	90.1
	2C	100–125	4.2	2.5	4.7	10.3	15.90	62.4	93.3
	3C	125–150	2.9	3.8	4.9	7.0	15.70	65.7	93.3
Average		0–150	3.4	2.9	5.3	7.9	15.4	65.1	93.7

TABLE 4. Coefficients of the percentage of unavailable water in soil grains (Table 3) to the percentage of grains in the soil mass (Table 1) = $\frac{\%H_2O \text{ in grains}}{\% \text{ of grains}}$

Locality	Horizon	Depth in cm	Diameter of grains in mm			
			<0.002	0.002–0.005	0.005–0.01	0.01–0.02
Profile1	Ap	0–25	10.2	3.0	1.1	0.8
(Gąbin),	Bw	25–50	7.6	2.0	0.4	0.5
Gostynin	Bw/C	50–75	2.3	1.5	0.4	0.4
county	C	75–100	2.4	1.2	0.4	0.3
	2C	100–125	2.3	0.9	0.7	0.4
	3C	125–150	2.4	1.1	0.5	0.3
Averge		0–150	4.5	1.6	0.6	0.5
Profile 2	Ap	0–30	7.0	3.5	0.6	0.9
(Wilanów)	Bw	30–60	3.2	2.7	6.6	0.6
Warsaw city	Bw/C	60–90	4.7	4.3	1.7	1.7
	CG1	90–120	4.4	4.5	1.1	0.3
	CG2	120–150	4.5	3.4	2.3	0.3
Average		0–150	4.8	3.7	2.5	0.8
Profile 3	Ap	0–25	5.5	3.9	1.7	0.5
(Kazuń Polski)	Bw	25–50	6.0	4.4	1.4	0.4
Modlin county	Bw/C	50–75	2.5	3.9	2.0	0.9
	C	75–100	3.3	9.6	5.1	5.2
	2C	100–125	7.3	13.2	6.9	1.9
	3C	125–150	3.5	9.2	3.7	1.6
Average		0–150	4.7	2.9	3.5	1.8

from the old terrace of the Vistula River (Profile 3), with oscillations from 2.1 to 11.7% in the genetic horizons (Table 3). According to the calculations, this fraction can bind only from 0.2 to 1.8 kg/m^2 of water unavailable to plants in all soil profiles (Table 5). The summary content of this water in the soil profiles down to 150 cm per 1 m^2 vary from 1.86 kg in the soil developed from glacial till (Profile 1) to 4.74 kg in the alluvial soil (Profile 2), thus indicating that soil with the highest content of the 0.01–0.005 mm fraction binds the lowest capacity of water unavailable to plants (Gąbin) (Table 1 and 5).

Grains 0.005–0.002 mm in diameter occur in the studied soils in very low quantities not exceeding 10% (Table 1). As a result, they have a low but significant contribution in the balance of fractions and bound water (Table 1 and 5). The percentage capacity of water unavailable to plants in this fraction varies from about 3.0 to 18.6% in the particular genetic horizons (Table 2). The fraction separated from soils of the old and present-day terrace of the Vistula River (Profile 2 and 3) is twice richer in water unavailable to plants than the fraction separated from glacial till (Profile 1) (Table 2).

Binding of water unavailable to plants by the fraction 0.005–0.002 mm is more even in the three profiles studied. It ranges from 9.2 to 21.0% (Table 3), despite variability in the absolute values (Table 2). In this fraction, microcapillaries smaller than 0.2 μm filled with water represent averagely 21 to 22% of the total porosity assumed as 100% in Profile 2 and 3. In turn, in soil developed from glacial till (Profile 1), the microcapillaries are only 8% of the total porosity. As assumed from the calculations, the fraction 0.005–0.002 mm may bind from about 5.0 to 12.0 kg/m^2 of water unavailable to plants in soil profiles down to 150 cm (Table 5). The genetic horizons of particular soils show large variability in the quantity of micro-capillaries below 0.2 μm, often regardless the content of this fraction (Table 1 and 5).

Grains <0.002 mm in diameter bind two to three times more water unavailable to plants in comparison to all remaining fractions of the studied soils (Table 2). Water content in the genetic horizons ranges from 23.8 to 97.5%. The capacity of water unavailable to plants decreases gradually in this fraction from horizons Ap down to 120 cm, to increase again in the deepest horizons 120–150 cm in all three profiles studied (Table 2). Most probably in this case there is an influence of organic humus compounds on the binding of water unavailable to plants and the increase of microporosity. In turn, the increase of the abundance of pores below 0.2 μm in diameter in the deepest horizons of all three profiles is difficult to explain. The contribution of this fraction (<0.002 mm) in the binding of water unavailable to plants in relation to all other fractions ranges from 60.5 to 80.7%, and the share of all other fractions (1–0.002 mm) is from 19.3 to 39.5% (Table 3).

Micropores in the diameter below 0.2 μm in the fraction <0.002 mm are in the range of 58% of total porosity in soil developed from glacial till (Profile 1). In turn, in the fractions separated from old and young alluvial soils (Profile 3 and 2), micropores represent from 80 do 94.2% of total porosity of this fraction.

Summing up, it is important to indicate the mutual relation between the content of the clay fraction <0.002 mm in the studied soil profiles to the depth of 150 cm per m^2, and the capacity of water unavailable to plants that can be bound in capillaries below 0.2 μm. Thus, in glacial till (Profile 1) the content of this fraction is 414 kg/m^2 down to 150 cm and the capacity of water in microcapillaries below 0.2 μm reaches 124 kg. In present-day alluvial soil (Profile 2) in the same volume of soil there is 174 kg of the clay fraction and 82.0 kg of water that can be bound in microcapillaries below 0.2 μm. Soil from the old Vistula terrace (Profile 3) in similar volumes contains 270 kg of the clay fraction and can bind 127 kg of water in the microcapillaries.

These data indicate that the ratio of water unavailable to plants to the content of particular fractions is identical in soils from the Vistula River valley (Wilanów and Kazuń) and reaches 0.47. In turn, in soil developed from glacial till (Gąbin) this ratio is much lower and reaches about 0.30. Factors that influence these regularities include the mineral composition of the clay fraction and the humus content.

Comparison of the percentage content of the particular grain size fractions in binding water unavailable to plants (Table 3) to the percentage content of each fraction in the soil mass (Table 1) gives specific coefficients (Table 4). The obtained coefficients vary between the soil profiles and within the genetic horizons. Very similar coefficients were noted in soil developed from glacial till (Profile 1) below horizons Ap and Bbr. In turn, in the old and young alluvial soils (Profile 3 and 2, respectively) these coefficients vary between the genetic horizons. Thus, the attempts undertaken by Trzecki (1968, 1974, 1976) related to the possible calculation of the content of different water types in soils based on the grain size composition do not fulfil the expectations. Oscillation of the obtained coefficients is in some cases multiple (Table 4).

The variable mineralogical composition of the grain size fractions, particularly the fraction <0.02 mm comprising various clay minerals with diverse structure and specific surface determines the possible binding of various forms of water in the range of pF from 2 to 7. Therefore, attempts of using grain size for the water characteristics of soils, as presumed from the results obtained on three different soils, are not prospective. Maybe other forms of water that are not bound by the mineralogical elements of the fractions, particularly <0.02 mm, can be calculated with the exclusion of microcapillaries below 0.2 μm. This, however, requires detailed studies with various soil kinds, types and species.

DISCUSSION

The assumption by Trzecki (1968, 1974, 1976) on the possible calculation of the capacity of various water types in soils based on the grain size composition cannot be confirmed. Drawing conclusions of this sort based on two soil samples from horizons Ap could not be reliable. The studies presented herein based

TABLE 5. Water capacity at pF=4.2 in the soil grain size fractions in kg/m^2 of the genetic horizon

Locality	Horizon	Depth in cm	Percent of grains in diameter in mm							<1 mm sum
			1–0.1	0.1–0.02	0.02–0.01	0.01–0.005	0.005–0.002	<0.002	Σ <0.02	
Profile1 (Gąbin), Gostynin county	Ap	0–25	1.12	1.18	0.28	0.36	0.92	9.21	10.77	13.07
	Bw	25–50	0.55	0.50	0.27	0.20	1.13	11.80	13.40	14.45
	Bw/C	50–75	0.30	0.38	0.16	0.24	1.46	31.04	32.90	33.58
	C	75–100	0.19	0.22	0.15	0.22	0.83	24.63	25.83	26.24
	2C	100–125	0.12	0.30	0.20	0.44	0.92	22.51	24.07	24.49
	3C	125–150	0.26	0.16	0.30	0.42	0.70	24.84	26.26	26.68
Averge		0–150	2.54	2.74	1.36	1.86	5.90	124.03	133.15	138.51
Profile 2 (Wilanów) Warsaw city	Ap	0–30	0.24	0.38	1.30	0.67	2.66	22.30	26.93	27.55
	Bw	30–60	0.07	1.46	2.04	1.80	4.34	18.60	26.76	28.31
	Bw/C	60–90	0.60	0.95	1.55	0.60	1.58	8.60	12.33	13.88
	CG1	90–120	0.36	0.72	0.80	0.81	2.20	15.94	19.75	20.83
	CG2	120–150	1.06	3.30	1.05	0.86	1.00	16.27	19.18	23.54
Average		0–150	2.36	6.81	6.74	4.74	11.78	81.71	104.99	114.14
Profile 3 (Kazuń Polski) Modlin county	Ap	0–25	1.00	2.00	0.87	1.13	1.62	30.42	34.04	37.04
	Bw	25–50	1.33	0.65	0.40	0.28	1.16	21.86	23.70	25.68
	Bw/C	50–75	0.90	0.81	0.56	0.33	0.90	28.50	30.29	32.00
	C	75–100	0.98	1.78	0.30	0.33	0.34	13.17	14.14	16.90
	2C	100–125	1.47	0.72	0.20	0.27	0.30	14.20	14.97	17.16
	3C	125–150	1.12	1.66	0.30	0.26	0.63	19.00	20.14	22.97
Average		0–150	6.80	7.62	2.63	2.60	4.95	127.15	137.33	151.75

on three complete soil profiles and focused only on water unavailable to plants, bound by forces pF>4.2, clearly indicated high variability in the genetic horizons. Thus, it is extremely difficult to determine the coefficients allowing to calculate the capacity of water bound by particular grain size fractions. Binding of water by a particular fraction does not depend only on its diameter, but as assumed from the studies of Waksmundzki et al. (1981), also on the mineralogical composition of the fractions, particularly fraction <0.02 mm. Fractions <0.02 mm correspond to binding of 96 to 98% of total water unavailable to plants in the studied soils (Table 3).

CONCLUSIONS

1. The main fractions binding water unavailable to plants in the studied soils are grains in the diameter <0.02 mm, among them grains <0.002 mm.
2. Fractions <0.02 mm bind from 90.1 to 98.8% of total water unavailable to plants in soils, and the clay fraction (<0.002 mm) alone binds from 52.1 to 80.1% of this water.
3. Binding water by fractions <0.02 mm significantly depends on their mineralogical composition. The presence of illite, chlorite or kaolinite considerably decreases the capacity of water unavailable to plants by even 40% in relation to fractions composed of smectites, vermiculites, and humus.
4. The capacity of water bound by forces pF=4.2 in the studied profiles are in the range of 114 to 151.7 kg/m^2 to the depth of 150 cm and 81.7 to 127 kg/m^2 in the clay fraction (<0.002 mm) alone to the depth of 150 cm.
5. Due to high variability of the capacity of water unavailable to plants in particular grain size fractions <0.02 mm resulting from the variable mineralogical composition of this fraction, coefficients allowing to calculate the capacity of water unavailable to plants in soil microcapillaries below 0.2 μm show very high oscillation and could not be applicable.

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Próba wykorzystania uziarnienia gleby do obliczania zawartości wody niedostępnej dla roślin

Streszczenie: Celem pracy była próba znalezienia możliwości obliczenia ilości wody niedostępnej dla roślin na podstawie uziarnienia gleb. Frakcje o średnicach <0,02 mm gromadzą od 90,1 do 98,8% całkowitej ilości wody niedostępnej dla roślin, a frakcja iłu koloidalnego (<0,002 mm) zatrzymuje od 52,1 do 80,1% tej wody. Gromadzenie wody we frakcjach <0,02 mm znacząco zależy od ich składu mineralogicznego. Obecność we frakcjach illitu, chlorytu oraz kaolinitu powoduje zmniejszenie ilości wody niedostępnej nawet o 40% w stosunku do frakcji zbudowanych ze smektytów, wermikulitów oraz próchnicy. Ze względu na duże zróżnicowanie ilości wody niedostępnej dla roślin w poszczególnych frakcjach granulometrycznych <0,02 mm wynikające ze zróżnicowania mineralogicznego tych frakcji nie udało się wyprowadzić współczynników pozwalających na obliczenie ilościowe w glebach wody niedostępnej dla roślin wiązanej w mikroporach <0,2 μm.

Słowa kluczowe: woda niedostępna dla roślin, skład granulometryczny, minerały ilaste