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Review

Database of Polish arable mineral soils: a review

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Abstract. The database of Polish arable mineral soils is presented. The database includes a lot of information about the basic properties of soils and their dynamic characteristics. It was elaborated for about 1 000 representative profiles of soils in Poland The database concerns: particle size distribution, organic carbon content, acidity-pH, specific surface area, hydrophobicity – solid-liquid contact angle, static and dynamic hydrophysical properties, oxidation-reduction properties and selected biological (microbiological) properties of soils. Knowledge about soil characteristics is indispensable for description, interpretation and prediction of the course of physical, chemical and biological processes, and modelling these processes requires representative data. The utility of simulation and prediction models describing phenomena which take place in the soil-plant-atmosphere system greatly depends on the precision of data concerning characteristics of soil. On the basis of this database, maps of chosen soil properties are constructed. The aim of maps is to provide specialists in agriculture, ecology, and environment protection with an opportunity to gain knowledge of soil properties and their spatial and seasonal variability.

Keywords: database, Polish mineral soils, physicochemical properties, biological properties

INTRODUCTION

Knowledge about soil characteristics is indispensable for description, interpretation, and prediction of the course of physical, chemical and biological processes and for modelling these processes, which requires representative data concerning various soil characteristics. The utility of simulation and prediction models describing phenomena which take place in the soil-plant-atmosphere system greatly depends on the precision of data concerning characteristics of soil. Therefore, over the last 25 years databases containing soil characteristics have been created (Thomasson, 1995; Várallyay, 1989, 1994; Wosten, 2000; Wosten *et al.,* 1998, 1999). On the basis of these databases, maps of chosen soil and environment properties have been constructed (Nemes, 2011; Santra *et al*., 2008; Taylor and Minasny, 2006; Wagner *et al*., 2001). The aim of datasets was to provide specialists in agriculture, ecology, and environment protection with an opportunity to gain knowledge of soil properties and their spatial and seasonal variability (Carsel and Parish, 1988; Leenhardt *et al*., 2006; Williams *et al.,* 1992).

Under a collaborative project of the Institute of Agrophysics, Polish Academy of Sciences in Lublin and the Institute of Land Reclamation and Grassland Farming in Falenty, the database of Polish arable mineral soil (DPAMS) samples was organized inspired by Glinski, Ostrowski, Stępniewska and Stępniewski, scientists at these institutions (Gliński *et al*., 1991).

The aim of database creation was to give a possibility of comprehensive characterization of soil as a medium of production processes in agriculture, making it possible to refer the results obtained to the structure of the soil cover of our country. Another important goal was to create a possibility of parallel gathering of the results of analyses of collected samples and to use the results for development of different kinds of databases.

CREATION OF THE POLISH ARABLE MINERAL SOIL SAMPLE SET

Soil agricultural maps at 1:5 000 000 and 1:25 000 scales distinguish a large number of soil taxonomic units (Witek, 1974). Since 1 200-2 000 soil units can be selected only in one province, it was necessary to choose samples from more important soils, which significantly affect cultivation and reflect the need for arable soil improvement. To meet this requirement, about 1 000 representative soil profiles localized throughout the country have been selected

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*Corresponding author e-mail: a.bieganowski@ipan.lublin.pl with respect to the variability and differentiation of the soil cover and the soils were grouped into 25 units (Table 1). Each unit includes one or two types and textural classes of soil. Soil agricultural maps elaborated by Witek (1974) were used for creation of these groups. The soil units occupied an area from 380 to 40 980 km^2. They are represented mainly by Cambisols, Luvisols and Podzols, derived from sands, loams, silts, and loess, as well as Gleysols, Fluvisols, Leptosols, and Phaeozems.

Spatial distribution of the soil profiles has been constructed by pointing out soil units, from which the samples should be taken in particular provinces and the number of profiles necessary to represent them (Fig. 1). The number of profiles (replications) in particular units, which was proportional to the area occupied by a given unit in the territory of Poland (from 22 to 186), allowed statistical elaboration of the analytical data and guaranteed credible results. The soil samples (in an undisturbed and disturbed state) were taken from:

Fig. 1. Location of soil profiles.

Table 1. Soil units of Poland (Gliński *et al*., 1991)

No.	Soil unit (derived from)	Surface area in (km^2)	Surface area in (%)	Quantity of profiles
1	Rendzic Leptosols (pure, calcaric rocks)	1 900	1.2	22
2	Rendzic Leptosols (mixed, calcaric rocks)	450	0.3	22
3	Haplic Phaeozems - silt	2 360	1.5	22
4	Haplic Luvisols and Dystric Cambisols - loose sands	40 980	27.0	186
5	Haplic Luvisols and Dystric Cambisols - light loamy sands	1 630	11.0	22
6	Haplic Luvisols and Eutric Cambisols - loamy sands	6 050	4.0	29
7	Eutric Cambisols - loamy sands over loams, Haplic Podzols - loamy sands	18 580	12.2	86
8	Eutric Cambisols and Haplic Podzols - light loams	18 970	12.5	88
9	Eutric Cambisols and Haplic Podzols - medium loams	9 370	6.2	50
10	Eutric Cambisols and Haplic Luvisols - heavy loams	1 210	0.8	22
11	Eutric Cambisols and Haplic Luvisols - loams	5 700	3.8	22
12	Haplic Luvisols and Distric Cambisols - gravels	880	0.6	22
13	Eutric Cambisols and Haplic Podzols - hydrogenic silts	7 390	4.9	44
14	Haplic Luvisols and Eutric Cambisols - loess	10 560	6.9	49
15	Haplic Luvisols and Eutric Cambisols - clays	500	0.3	22
16	Haplic Luvisols and Eutric Cambisols - loams and skeleton loams	1 680	1.1	22
17	Haplic Luvisols and Eutric Cambisols - loams	1 920	1.3	44
18	Haplic Luvisols and Eutric Cambisols - clays	380	0.3	22
19	Haplic Luvisols and Eutric Cambisols - silt	2 010	1.3	22
20	Eutric Fluvisols - loams and silts	5 050	3.3	44
21	Distric Fluvisols - sands	2 110	1.4	22
22	Eutric Fluvisols - light silty loam	700	0.4	22
23	Mollic Gleysols - loams and silts	6 600	4.3	44
24	Mollic Gleysols - sands	3 940	2.6	22
25	Terric Histosols	1 140	0.7	22

- the surface (arable) layer with accumulated organic matter (0-20 cm),
- the subsurface layer characterized by mineralization of organic matter transported to them (20-40 cm),
- the subsoil with predominant natural features of the components of mineral soils (below 40 cm).

The samples are stored at the Institute of Agrophysics PAS in Lublin.

Precise localization of the profiles (name of place and geographic coordinates) and the description thereof offers a possibility of cyclic return to sampling places at optimal time intervals, which is a basis for soil monitoring.

The results of the measurements were introduced to the Soil Cartographic Database and, after computer processing with the use of the statistical methods, converted to the spatial characteristics of the soil units which allowed generating computer maps (Gliński and Ostrowski, 2011; Ostrowski *et al*., 1998, 2012). The basis for generation of a computer map image is a procedure based on an algorithm:

$$< J_{g1} \in \_ O_n , J_{g2} \in O_n , \ldots\ldots\ldots\ldots , J_{gm} \in O_n > \in TJ_n ,$$

where: TJ_n – the n-th topical unit, O_n – the *n*-th soil evaluation, J_{g1},......, J_{gm} – soil units belonging to the *n* evaluation.

In this way, maps of hydrophysical (33), oxidation-reduction (35) and specific surface area (4) of Polish arable mineral soils were created at a country scale (Gliński *et al*., 2000; Stawiński *et al*., 2000; Stępniewska *et al*., 1996-1997; Walczak *et al*., 2002d).

This paper presents chosen characteristics of Polish arable soils elaborated for the surface layer.

DATA COLLECTION

Since, as mentioned earlier, the DPAMS was created in order to collect soil samples representative for Poland, all the following data can be considered as representative for Polish soils. These analytical data concerned:

- particle size distribution,
- organic carbon content and pH,
- specific surface area and hydrophobicity of soils,
- hydrophysical properties of soils,
- oxidation-reduction properties of soils,
- biological (microbiological) properties of soils.

Particle size distribution

Particle size distribution (PSD) is one of the most important soil characteristics. It influences (directly and indirectly) many soil properties such as hydrological properties (Jadczyszyn and Niedźwiecki, 2005; Toth *et al*., 2006; Tramontini *et al*., 2012), air-water conditions (Makó and Elek, 2006; Skierucha *et al*., 2006), thermal conductivity (Usowicz *et al*., 2008), microbial activity (Brzezińska *et al*., 2012; Frąc *et al*., 2012; Nosalewicz and Nosalewicz, 2011) or gas-exchange (Brzezińska *et al*., 2011a; Włodarczyk *et al*., 2011; Wolińska *et al*., 2011). PSD can be the basis for calculation of other soil characteristics such as fractal dimension (Bieganowski *et al*., 2013; Gunal *et al*., 2011; Usowicz and Lipiec, 2009) or modelling (Lamorski *et al*., 2008; Wei Shangguana *et al*., 2012). It can be used for characterization of soil and geomorphological processes (Długosz *et al*., 2009; Dobrowolski *et al*., 2012; Kabala and Zapart 2012; Józefaciuk *et al*., 2006; Waroszewski *et al*., 2013). PSD can be also the basis of other soil measurements (Brogowski and Kwasowski, 2012; Bryk, 2012).

The PSD of soils collected in the DPAMS was measured using the Cassagrande method. This method is a variant of the hydrometer method (ISO 11277:2009) still used in laboratories (Mocek *et al*., 2012; Molinaroli *et al*., 2011; Schjonning *et al*., 2012). It is based on Stokes law, which describes sedimentation of soil particles. The modification involves construction of a hydrometer (the hydrometer is calibrated in the percentage of the mass in the total mass of suspension).

In accordance with the PSD determination standards binding in Poland at the time when the DPAMS was created, all samples were air dried and sieved through a 1mm sieve. The division into soil particle size fractions according to the old Polish Society of Soil Science is shown in Table 2. This classification was valid in Poland until 2008.

The summary of the results of the PSD of all soils collected in the DPAMS is shown in Fig. 2 and soil texture classes in Table 3. It can be seen that most soils in Poland belong to sandy and silty soils. Only a small percentage of the soils are clayey soils.

For two reasons (new classification of soil on the basis of PSD and new methods for PSD determination) the new measurements of all soil collected in DPAMS are planned.

Table 2. Division into soil particle size fractions according to the old Polish Soil Science Society (PTGleb., 2008) classification (This distribution was valid in Poland until 2008)

Fraction	Subfraction	Diameter (mm)
Sand		1.00 ÷ 0.10
	Coarse	1.00 ÷ 0.50
	Medium	0.50 ÷ 0.25
	Fine	0.25 ÷ 0.10
Silt		0.10 ÷ 0.02
	Coarse	0.10 ÷ 0.05
	Fine	0.05 ÷ 0.02
Clay		< 0.02
	Coarse silty clay	0.020 ÷ 0.005
	Fine silty clay	0.005 ÷ 0.002
	Colloidal clay	< 0.002

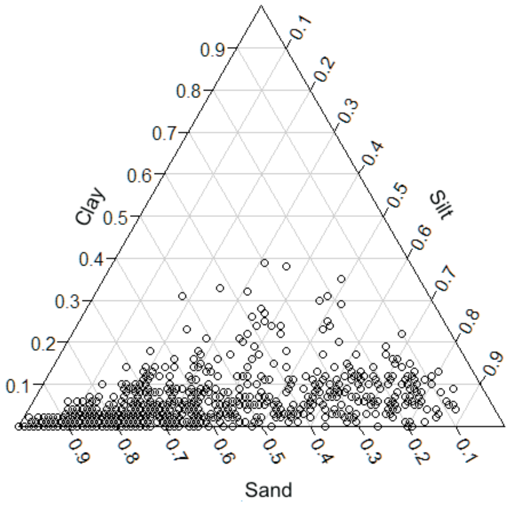

Fig. 2. Texture of soils collected in DPAMS.

Table 3. Texture classes of soils from the database according to the actual classification of Polish Soil Science Society (PTGleb., 2008)

Texture classes	% of texture class in the database
pg - loamy sand	25.0
gp - sandy loam	23.6
pyg - loamy silt	16.7
pl - loose sand	10.2
ps - weakly loamy sand	10.0
gl - light loam	4.6
gz - loam	4.0
pyi - clay silt	2.9
pyz - proper silt	1.7
gi - clay loam	0.8
gpi - sandy clay loam	0.3
gpyi - silty clay loam	0.2

Table 4. Organic carbon content (C_{org}) in Polish arable soils

Soil type	C_{org} (%)		
	Average	Minimum	Maximum
Podzols	0.83	0.14	4.9
Cambisols	0.90	0.03	3.21
Fluvisols	1.27	0.36	2.72
Rendzic Leptosols	1.31	0.36	2.88
Phaeozems	1.32	0.83	2.1
Gleysols	1.38	0.34	4.26
Histosols	2.26	0.15	8.34

To avoid misunderstanding, the USDA and Polish classification for soil fractions and texture will be used (PTGleb, 2008; Soil Survey Division Staff, 1993). The laser diffraction method (LDM) will be applied for the measurements (ISO 13320:2009). The authors realize that the textures obtained by laser diffractometry are different in some cases from those obtained with the sedimentation methods (Hajdók *et al*., 2012; Ryżak and Bieganowski, 2010). However, the standardization of the procedure (Ryżak and Bieganowski, 2011; Sochan *et al*., 2012) provides repeatable and reproducible results, and the use of LDM (being increasingly used in different laboratories) allows comparison of the results with other studies (Grangeon *et al*., 2012; Rathossi *et al*., 2012; Vendelboe *et al*., 2012).

Organic carbon content and pH

One of the basic soil characteristics are the organic carbon content and pH. These properties determine soil fertility as well as virtually all processes occurring in the soil. Soils collected in the DPAMS are characterized by a diverse organic C content and pH value. The average amount of C_{org} in analyzed soils ranged from 0.83 to 2.26%. The minimum amount of C_{org} was observed in Cambisol (0.03%), while the maximum in Histosol (8.34%) (Table 4).

Taking pH value into account, Polish soils range from acidic (Podzols – 4.27) to alkaline soils (Rendzic Leptosols – 8.45).

Specific surface area

Studies of the surface chemistry of solids frequently involve determination of the specific surface area. Many investigators have attempted to measure the surface area as a means of better description of soil materials under study or better understanding of a particular process or reaction. The solid phase of a soil is a mixture of different inorganic constituents *eg* nonporous materials of different size and shape, porous materials with microcapillaries or pores and phyllosilicates with an interlayer structure, as well as organic species, mainly organic matter. Different kinds of the surface area may be found in soil (the geometric, internal, interlayer, external, total surface area). The total surface area is sum of the surface area of external, internal, and surface area of organic matter. The total, external, and internal surface areas are the main types of the specific surface that can be used to characterize each adsorbent. The specific surface area of a soil sample is the combined surface area of all the particles in the sample determined using some experimental technique and expressed per unit mass of the sample. As its definition implies, the term ‘specific surface area’ is an operational concept. Polar adsorbates include water vapour, ethylene glycol or ethylene glycol monoethyl, which are employed to measure the total surface area. Typical nonpolar adsorbates include nitrogen, argon, krypton and they are applied to measure the external surface area. In most cases, the total surface area exceeding the external one is measured (Sokołowska, 2011).

The specific surface area of surface layers of Polish soils was determined by the adsorption method using the Brunauer-Emmet and Teller (BET) equation (PN-Z-19010-1, 1997). The average values of the total (from H_2O-water vapour isotherms) and external (from N_2 isotherms) specific surface area are shown in Figs 3 and 4 (Stawiński *et al*., 2000).

The maximum values of the total surface area $S(H_2O)$ were found for soil units number 1, 10, 15-18, 20, 22, and 23 (Table 5, Fig. 3). The values of $S(H_2O)$ depend on the content of granulometric fractions, the composition of clay fraction, surface cations, and agricultural practice (Sokołowska, 1989, 2011; Sokołowska *et al*., 1993, 1999, 2002). The effect of SOM on the specific surface area is not unequivocal (Sokołowska *et al*., 1993, 2004, 2009). The maximum values of the external surface area (Table 6, Fig. 4) were found for soil units number 1, 10, 14, 15 and 18, *ie* for Leptosols and soils derived from heavy loam, loess, and clays. The geostatistical methods employed to soils on the territory of Poland indicated anisotropy of the total surface area in soils with a trend toward the geographical East to West directions. Similar tendencies were exhibited by the spatial distributions of sand, silt and, clay fractions (Sokołowski *et al*., 2012).

Table 5. The ranges of the value of the total specific surface area of surface layer for soil units

Ranges of the value of the total specific surface area (m^2 g^{-1})	Soil units (derived from)
< 14	Haplic Luvisols and Dystric Cambisols (loose sands)
14 - 16	Eutric Cambisols (loamy sands over loams); Haplic Podsols (loamy sands); Eutric Cambisols and Haplic Podzols (hydrogenic silts)
16 - 20	Haplic Luvisols and Dystric Cambisols (light loamy sands); Haplic Luvisols and Eutric Cambisols (loamy sands); Eutric Cambisols and Haplic Podzols (light loams); Haplic Luvisols and Distric Cambisols (gravels)
20 - 24	Eutric Cambisols and Haplic Podzols (medium loams); Eutric Cambisols and Haplic Podzols (hydrogenic silts); Mollic Gleysols (sands)
24 - 28	Eutric Cambisols and Haplic Podzols (medium loams); Eutric Cambisols and Haplic Luvisols (loams); Terric Histosols
28 - 32	Leptosols (mixed); Haplic Phaeozems (silt); Haplic Luvisols and Eutric Cambisols (loess); Distric Fluvisols (sands)
32 - 42	Haplic Luvisols and Eutric Cambisols (loams); Haplic Luvisols and Eutric Cambisols (silt); Mollic Gleysols (loams and silts)
42 - 50	Eutric Cambisols and Haplic Luvisols (heavy loams); Eutric Fluvisols (light silty loam)
50 - 60	Haplic Luvisols and Eutric Cambisols (clays); Haplic Luvisols and Eutric Cambisols (loams and skeleton loams); Haplic Luvisols and Eutric Cambisols (clays)
> 60	Leptosols (pure); Eutric Fluvisols (loams and silts)

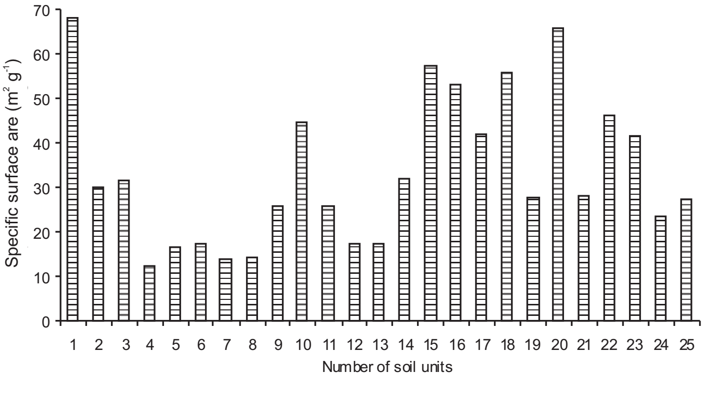

Fig. 3. Average total specific surface area for soil units.

Table 6. The ranges of the value of the external specific surface area of surface layer for soil units

Ranges of the value of the total specific surface area (m^2 g^{-1})	Soil units (derived from)
< 4	Haplic Luvisols and Dystric Cambisols (light loamy sands); Eutric Cambisols and Haplic Podzols (hydrogenic silts)
4 - 5	Haplic Luvisols and Dystric Cambisols (loose sands); Haplic Luvisols and Eutric Cambisols (loamy sands); Eutric Cambisols (loamy sands over loams), Haplic Podsols (loamy sands); Mollic Gleysols (sands); Terric Histosols
5 - 6	Eutric Cambisols and Haplic Podzols (light loams); Eutric Cambisols and Haplic Podzols (hydrogenic silts); Haplic Luvisols and Distric Cambisols (gravels); Eutric Cambisols and Haplic Podzols (hydrogenic silts); Distric Fluvisols (sands)
6 - 7	Leptosols (mixed); Eutric Cambisols and Haplic Podzols (light loams); Eutric Cambisols and Haplic Podzols (medium loams); Eutric Cambisols and Haplic Luvisols (loams); Mollic Gleysols (loams and silts)
7 - 10	Haplic Phaeozems (silt); Eutric Cambisols and Haplic Podzols (medium loams; Haplic Luvisols and Eutric Cambisols (silt); Eutric Fluvisols (light silty loam)
10 - 13	Eutric Cambisols and Haplic Luvisols (heavy loams); Haplic Luvisols and Eutric Cambisols (loess); Haplic Luvisols and Eutric Cambisols (loams and skeleton loams); Haplic Luvisols and Eutric Cambisols (loams); Eutric Fluvisols (light silty loam)
> 13	Leptosols (pure); Haplic Luvisols and Eutric Cambisols (clays); Haplic Luvisols and Eutric Cambisols (clays); Eutric Fluvisols (loams and silts)

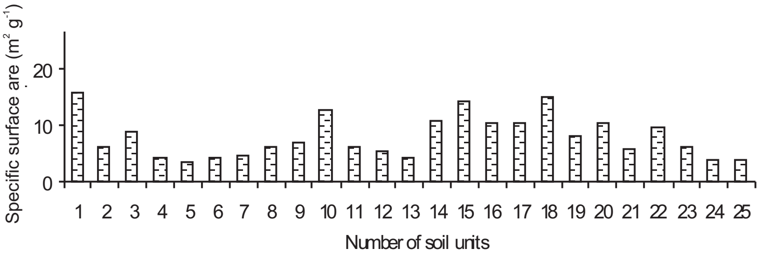

Fig. 4. Average external specific surface area for soil units.

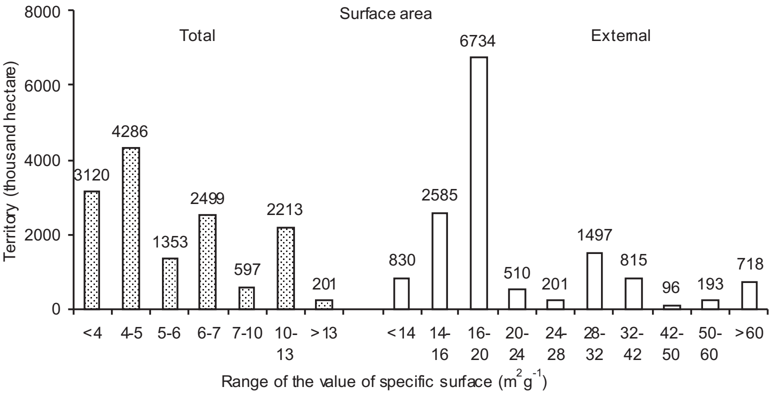

Fig. 5. Areas of Poland soils with different value of specific surface area.

Generally, soils from the highland and mountain zone exhibit higher values of the surface area (Stawiński *et al.*, 2000). The soils on the remaining part of the territory of Poland are characterized by the total surface area up to 20 m^2g^{-1} and the external surface area up to 7 m^2g^{-1} (Tables 5, 6). However, within this territory there are enclaves with higher values of $S(H_2O)$ – Żuławy Wiślane, Równina Błońsko-Sochaczewska and Kujawy. Quantitative analysis of the values $S(H_2O)$ and $S(N_2)$ suggests that the differences in the surface area for soil units are connected with the granulometric

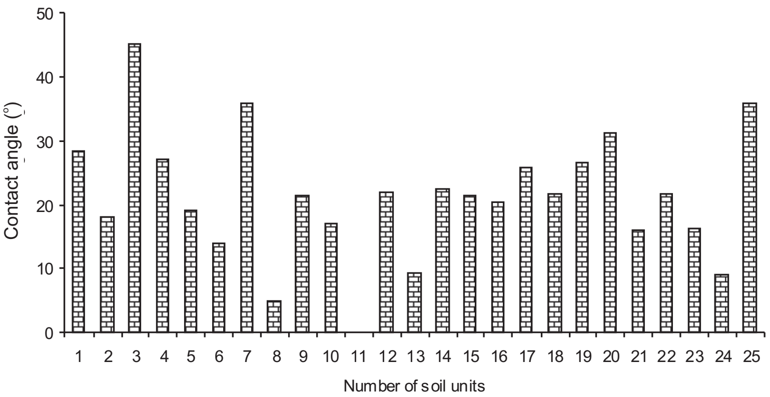

Fig. 6. Water contact angles for soil units (no 11 - not investigated) (Całka, 2009).

composition of soils. Soils with the total and external surface area in the range 16-20 and 4-5 m^2g^{-1} dominate on the territory of Poland (Fig. 5). Noteworthy, soils exhibiting the external surface area up to 4 m^2g^{-1} cover a big area (about 3 mln ha) as well.

Hydrofobicity

Soils in Poland have a generally hydrophilic character (Całka, 2009) and the values of the contact angle range from 4 to 45° (Fig. 6). For Cambisoils, the contact angles are in the range of 5-36°, for Fluvisols 6-31°, for Leptosols 12.4-28.4°, and for Phaeozems 4.4-45.2°. The maximum and minimum values of the contact angle were found for soil units number 7, 20, 25, and 8, 13, 23, respectively. The contact angles of soils are associated with the content of the granulometric fraction and organic matter.

Hydrophysical properties

The hydrophysical properties of soils *ie* water retention and hydraulic conductivity in both saturated and unsaturated zones not only shape soil water balance but also decide the conditions for plant growth, development and yield. They also determine water availability for the plant root system and the transfer of water with chemical compounds dissolved in it into deeper layers. The above compounds are nutrients indispensable for plant growth as well as all kinds of other chemical substances which pose a threat to the environment. Humidity conditions in the soils exert a decisive influence on their thermal and mechanical properties which shape the temperature in the soil profile and also the conditions and efficiency of the agrotechnical mechanical treatments applied. A knowledge of the hydrophysical properties is necessary for the interpretation and forecasting of practically all physical, chemical and biological processes which occur in the soil since the modelling of these processes requires representative data on the soil hydrophysical characteristics (Lamorski *et al.*, 2001, 2002; Skierucha *et al.*, 2012; Sławiński, 2003; Walczak *et al.,* 1999, 2002d; Witkowska-Walczak *et al.*, 2004, 2012).

The measurements of soil water retention curve (SWRC) in drying process were done within the range of potentials from 0.1 kJ m^{-3} (pF 0) to 1 500 kJ m^{-3} (pF 4.2) for 11 points in the process of drying. Standard pressure chambers (Soil Moisture, Santa Barbara, California, USA) and Richards method were used (Witkowska-Walczak *et al.*, 2012). Water content was expressed in the volumetric units (% m^3 m^{-3}), since it takes into consideration soil compaction and allows for calculation of water resources (water balance). It was assumed that for Polish conditions (Walczak *et al.,* 2002d):

- full water saturation of soil takes place at 0.1 kJ m^{-3} (pF 0),
- field water capacity (FWC) is at 16 kJ m^{-3} (pF 2.2),
- start of plant growth inhibition is at 100 kJ m^{-3} (pF 3),
- wilting point is at 1 500 kJ m^{-3} (pF 4.2) (all are shown in Table 7),
- available water capacity (AWC) (amount of water available for plants) is water content bound in soil with a potential from 16 kJ m^{-3} (pF 2.2) to 1 500 kJ m^{-3} (pF 4.2) (Fig. 7),
- amount of water easily available for plants is water content bound in soil with a potential from 16 kJ m^{-3} (pF 2.2) to 100 kJ m^{-3} (pF 3) and amount of water difficulty available for plants – from 100 kJ m^{-3} (pF 3) to 1 500 kJ m^{-3} (pF 4.2) (Fig. 7).

The saturated hydraulic conductivity was measured with a constant head method using the ICW permeameter (Eijkelkamp-Agrisearch Equipment, Giesbek, the Netherlands), whereas the unsaturated hydraulic conductivity – using instantaneous profiles method (IPM) based on the measurements of water content and water potential in the chosen layers of the soil sample by means of a TDR set in the drying process (Sławiński, 2003; Walczak *et al.,* 2004ab). Hydraulic conductivity was investigated in the laboratory at various water content expressed by soil water potential (Table 7):

- 0.1 kJ m^{-3} (pF 0) – full water saturation,
- 16 kJ m^{-3} (pF 2.2) – field water capacity,
- 100 kJ m^{-3} (pF 3) – start of plant growth inhibition.

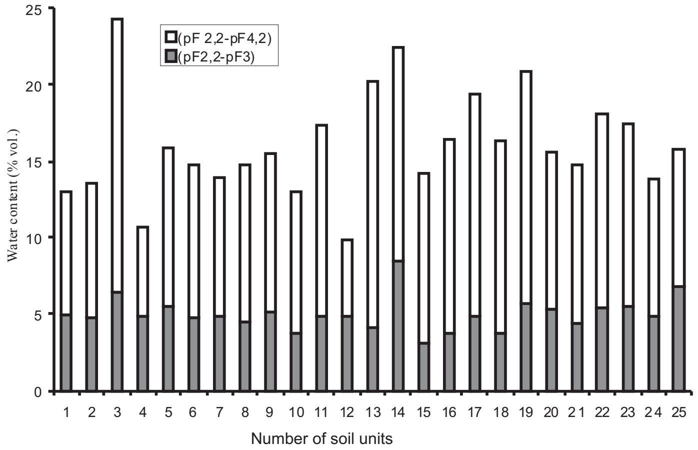

Fig. 7. Available water capacity (AWC) (amount of water available for plants, from 16 kJ m^{-3} (pF 2.2) to 1 500 kJ m^{-3} (pF 4.2), amount of water easily available for plants (pF 2.2-pF 3) and amount of water difficulty available for plants (pF 3-pF 4.2) (Witkowska-Walczak *et al*., 2012).

Table 7. Water content and hydraulic conductivity ranges at chosen soil potentials (pF) for soil units (Walczak *et al*., 2002d; 2012)

Number of soil units	Water content (% vol.)				Hydraulic conductivity (cm day^{-1})		
	pF 0	pF2.2	pF3	pF4.2	pF 0	pF 2.2	pF 3
1	45-50	30-35	30-35	20-25	>1000	0.05-0.1	0.001-0.005
2	40-45	20-25	15-20	5-10	5-500	0.1-0.5	0.001-0.005
3	50-55	30-35	25-30	5-10	500-1000	0.1-0.5	0.005-0.001
4	40-45	5-10	5-10	0-5	>1000	0.05-0.01	0.001-0.005
5	40-45	15-20	10-15	0-5	5-500	0.1-0.5	0.001-0.005
6	40-45	20-25	15-20	5-10	500-1000	0.1-0.5	0.001-0.005
7	35-45	15-25	10-20	0-10	500-1000	0.1-0.5	0.001-0.005
8	35-40	20-25	15-20	5-10	5-500	0.1-0.5	0.001-0.005
9	35-40	20-25	15-25	5-10	500-1000	0.05-0.1	0.001-0.005
10	35-40	25-30	25-30	15-20	>1000	0.01-0.05	0.01-0.005
11	35-40	20-25	15-20	5-10	>1000	0.01-0.05	0.01-0.005
12	35-40	10-15	5-10	0-5	>1000	0.05-0.1	0.01-0.005
13	40-45	25-35	15-25	0-10	>1000	0.1-0.5	0.01-0.005
14	45-50	30-35	25-30	5-10	>1000	0.1-0.5	0.001-0.005
15	40-45	35-40	30-35	20-25	>1000	0.01-0.05	0.001-0.005
16	40-45	30-35	30-35	15-20	>1000	0.1-0.5	0.001-0.005
17	40-45	30-35	25-30	10-15	500-1000	0.05-0.1	0.001-0.005
18	45-50	35-40	30-35	20-25	>1000	0.01-0.05	0.001-0.005
19	45-50	35-40	30-35	10-15	5-500	0.05-0.1	0.001-0.005
20	40-45	35-40	30-35	20-25	500-1000	0.01-0.05	0.001-0.005
21	40-45	20-25	15-20	5-10	500-1000	0.1-0.5	0.001-0.005
22	45-50	30-35	30-35	10-15	>1000	0.01-0.05	0.001-0.005
23	40-45	25-30	25-30	10-15	>1000	0.05-0.1	0.001-0.005
24	45-50	20-25	15-20	5-10	500-1000	0.1-0.5	0.001-0.005
25	45-50	20-25	15-20	0-5	>1000	0.1-0.5	0.001-0.005

The elaboration of database for hydrophysical characteristics of Polish soils allowed determination of their total and differential porosity (Walczak *et al.*, 1999, 2002d; Witkowska-Walczak *et al.*, 2003). The amount of large pores (dia >18.5 µm, pF0-pF2.2) in the surface layer of Polish arable soils reaches maximum values (28.6% vol.) in soils derived from light loamy and loose sands. Slightly lower values (28.0, 24.0, and 23.3%) are noticed in soils derived from gravel, Gleysols derived from sands and Histosols. The minimal values of the large pores were found in Cambisols and Luvisols derived from clays (6.1%) and heavy loam (9.5%). At increasing depths the maximum and minimum numbers of large pores were noticed in the same soils as was the case for the surface layer, but the maximum values increased about 3-5% and the minimum values decreased about 1-2%. Generally in other Polish soils, a decrease in the amount of large pores was observed, both in the subsurface layer and in the subsoil as compared to the surface layer. The amount of medium pores (18.5< dia <0.2 µm, pF2.2-pF4.2) changed in the surface layer from 26.3 to 8.2%, in the subsurface layer from 24.5 to 4.4% and in the subsoil from 27.4 to 2.1%. It reached the highest values in Pheaozems as well as in Cambisols and Luvisols derived from silt of water origin, loess and loess-like materials, whereas the lowest values were observed for Cambisols, Luvisols and Podzols derived from light loamy sands, loose sands as well as Cambisols and Luvisols derived from gravel. Likewise the large pores, the amount of medium pores generally decreases with depth of the soil profiles. The amount of small pores (dia <0.2 µm pF higher than 4.2) was the largest for soils derived from clay, lithic rocks, Leptosols (pure) as well as Cambisols and Luvisols derived from heavy loam (23.4-32.7%), whereas it was the smallest (1.4-1.7%) for Gleysols and Luvisols derived from gravel and sand.

Field water capacity

The field water capacity (FWC) of Polish soils varies from 3.9 to 45.5%, vol. in relation to soil units (Walczak *et al.*, 2002ad; Witkowska-Walczak *et al.*, 2012).The values obtained for FWC in soil samples belonging to individual soil units were subordinated to 5% intervals (Walczak *et al.*, 2002ab; Witkowska-Walczak et al., 2003). Such subordination of study results help to carry out comparative analysis of property studies both in relation to FWC and the recognition of factors conditioning its variability and differentiation. The above analysis showed that FWC of arable soils showed considerable differentiation in relation to soil units and considerably lower differentiation in soil profiles of individual soil units that did not exceed 10%. Loamy soils on a lighter substrate were an exception, as the FWC difference between the layers reached up to 20%. FWC values are differentiated to the highest degree by granulometric distribution. An obvious confirmation of the above conclusion is FWC of gravel (>5 -15%) and clay (35-50%) soils as well as soils with a differentiated texture in soil profile such as Cambisols derived from light loam (15-30%) as compared to soils with a uniform granulometric distribution, *ie* Phaeozems derived from loess (30-35%).

The analysis of the absolute FWC values suggested a division of the arable soils into three groups of soils with:

- low FWC values (below 20%),
- medium FWC values (20-30%),
- high FWC values (above 30%).

In the group with the lowest field water capacity values there are soils formed from sand and gravel, and Fluvisols (light). The group with the highest FWC included Leptosols (pure), Phaeozems, Fluvisols (medium and heavy), Cambisols derived from loess and loam, and weathering soils (mountain soils). The remaining soils, mainly formed of post-glacial formations, belonged to soils with medium field water capacity (Walczak *et al.*, 2001ab; Witkowska-Walczak *et al.*, 1999, 2000ab; Włodarczyk and Witkowska-Walczak, 2006).

Available water capacity

The available water capacity (AWC) in Polish arable soils was found from 2.1 to 27.2% vol. in relation to soil units (Walczak *et al.*, 2002b; Witkowska-Walczak *et al.*, 2003). The values of AWC, *ie* content of water bounded with potentials 16-1 500 kJ m^{-3}, obtained for the soil samples from individual soil units were subordinated to 3% intervals (Walczak *et al.*, 2002ac). A comparative analysis of results obtained showed that the terminal AWC *ie* 2.1% vol. for the subsoil of Cambisols derived from gravel and 27.2% vol. for subsoil of Phaeozems differed 13-fold. However, AWC for most of the soil units with regard to individual layers ranged from 12 to 15% and from 15 to 18%. The lowest AWC of 0-3, 3-6 and 6-9% was reported in soils derived from sand and gravel. Soils derived from clay and clayey silts had medium AWC and the highest AWC from the intervals of 18-21, 21-24, 24-27 and 27-30% were observed in soils derived from silt. AWC for soils formed from silt of water origin in deeper layers decreased, and in soils derived from eolic silt, the same values increased. The relation between AWC and humus content was only generally confirmed. AWC in Leptosols, which are rich in organic matter, was lower than in other soils with similar granulometric distribution, which may point to the fact that mineral soil composition can be of greater importance for formation of water regime by soil.

The arable soil profiles can be divided into three groups for general determination of their characteristic values of AWC:

- soils with low potentially useful retention (predominance of PUR < 12%);
- soils with medium potentially useful retention (predominance of 12% < PUR < 21%);

- soils with high potentially useful retention (predominance of 21% < PUR < 30%).

The first group includes soils derived from light clayey sand and loose gravels. The third group includes soils derived from silts and loess. The remaining soils are characterized by medium resources of water available for plants and they are predominant in the country.

Water available for plants

The amount of water easily available for plants, *ie* water bounded with potentials 16-100 kJ m^{-3}, in Polish arable soils is presented in Fig. 7 (Witkowska-Walczak *et al.,* 2003). It can be clearly noticed that Polish soils retain a very small quantity of this category of water. The amount of water easily available for plants varies from 2.2 to 7.1% vol. in the surface layer. Generally, the maximum amount of water was observed for Phaeozems, Cambisols and Luvisols derived from silt.

The amount of water available for plants – but only with difficulty, *ie* water bounded with potentials 100-1 500 kJ m^{-3} (Fig. 7), is much larger than water which is easily available and in the surface layer varies from 4.4 to 19.8% vol. The maximum quantity of this category of water is retained in Phaeozems, soils derived from silt and lithic rock as well as Fluvisols. Generally, the amount of water available for plants – but only with difficulty – decreases with the increase of the depth of the soil profiles.

The analysis of results shows that both varying porosity and the amount of water available for plants are connected with the parent materials and, consequently, with the granulometric composition of soils. It is a very important that Polish soils retain a very small quantity of water available for plants – less than 9% vol. This phenomenon contributes to the very unfavourable conditions for plant production in Poland.

Hydraulic conductivity

The values of hydraulic conductivity (k) measured in Polish soils ranged from 0.00087 to 5 900 cm day^{-1} (Sławiński *et al*., 2000ab; Walczak *et al.,* 2001, 2002c,d). The hydraulic conductivity of the surface layer was investigated at various intervals (Table 7). At full water saturation (pF 0) of the arable layer, a majority of the soils showed the highest level of hydraulic conductivity (k >1000 cm day^{-1}). Leptosols (pure), Luvisols derived from loose sands, clayey sand or clays and Histosols also belong to the above group. The lowest hydraulic conductivity ($5<k<500$ cm day^{-1}) was also characteristic of soils with an extremely different granulometric composition. Cambisols derived from clayey sands and light clays as well as Luvisols derived from silts of water origin also belong to this latter group, whereas Cambisols derived from the same parent material are characterized by the highest values of this coefficient (k>1000cm day^{-1}). At the soil water potential representing field water capacity (pF 2.2), most of the soil units are also characterized by relatively high values of hydraulic conductivity ($0.1 < k < 0.5$ cm day^{-1}). Most often these soil units were different from the previous cases. For example, Fluvisols (light and medium) as well as clayey soils at the full saturation level (pF 0) had the highest values of hydraulic conductivity and the lowest obtained values at pF 2.2. Luvisols derived from loose sands and clayey sands were characterized by a similar value, whereas Cambisols on loess and Fluvisols are characterized by the highest hydraulic conductivity at both values of the soil water potential.

At the soil water potential (pF 3) representing the beginning of plant growth inhibition, a predominant number of soil units fell into a group with $0.001 < k < 0.005$ cm day^{-1}. Only one soil unit, Rendzinas (pure), is characterized by the lowest hydraulic conductivity in this soil moisture regime, and three soil units are characterized by the highest value thereof.

At water saturation of the arable layer, a predominant proportion of soils showed the highest level of hydraulic conductivity (k >1000 cm day^{-1}). Leptosols (pure), soils derived from loose sands and clayey sand or clays, and Histosols belong to this group. The lowest hydraulic conductivity ($5 < k < 500$ cm day^{-1}) was also characteristic for soils with an extremely different granulometric composition. The soil derived from clayey sands and light clays as well as Luvisols derived from silts of water origin also belong to the latter group, whereas Cambisols derived from the same formation (parent material) are characterized by the highest values of k (k > 1000 cm day^{-1}).

At a soil water potential corresponding to field water capacity pF 2.2, a majority of soil units are also characterized by relatively highest hydraulic conductivity ($0.1 < k < 0.5$ cm day^{-1}). Most often these are soil units different than the other cases. For example, Fluvisols (light and medium) as well as clayey soils at saturation pF 0 had the highest hydraulic conductivity, and at pF 2.2, the lowest values were obtained. Luvisols derived from loose sands and clayey sands are characterized by a similar value, whereas Cambisols on loess and Histosols are characterized by the highest hydraulic conductivity at both values of the soil water potential.

At soil water potential pF 3 representing the beginning of plant growth inhibition, a predominant number of soil units fell into a group with $0.001 < k < 0.005$ cm day^{-1}. Only one soil unit, Leptosols (pure), was characterized by the lowest k value at this soil humidity, and three soil units exhibited highest hydraulic conductivity.

Oxidation-reduction properties

Oxidation-reduction (redox) processes caused mainly by microorganisms are one of the most important processes in soils. They affect many soil properties, plants, and environment (Gliński and Stępniewski, 1985; Gliński *et al*., 2012; Stępniewska, 2011; Stępniewska *et al*., 1996). Redox processes in soils are expressed by the redox potential (Eh), which may reach values from +700 mV for well aerated soils

to -400mV in highly reduced, flooded soils. The ability of the soil to maintain its Eh is a measure of soil resistance to reduction (Gliński and Stępniewska, 1986; Stępniewska, 1988, 1994) and is defined as time (in days) during which Eh of a soil sample under fixed laboratory conditions (entirely flooded with water, at a given temperature) drops to the value of +400 mV corresponding to nitrate decomposition (indicator t_{400}) or to the value of +300 mV corresponding to reduction of iron and manganese (indicator t_{300}). These indicators are characteristic and comparable features of various soils. With the use of the database measurements of Eh in soil samples, the t_{400} and t_{300} indicators of soil resistance to reduction were determined (Stępniewska *et al*., 1997). The following temperatures reflecting thermal conditions of vegetation in Poland were adopted:
+4°C – beginning of the vegetation season,
+10°C – intensive (spring) plant growth,
+15°C – an average temperature of the vegetation season,
+20°C – summer conditions (full growth).

Measurements of the t_{300} and t_{400} values were made for nearly all 1 000 soil profiles at a temperature 20°C. The mean values of t_{300} in the surface layers ranged from 0.2 to 4.4 days, in the subsurface layers – from 0.7 to 7.4 days, and in the subsoil – from 0.8 to 12 days. The mean t_{400} values in the surface layers were lower and ranged from 0 to 1.7 days, in the subsurface layers – from 0 to 2.7, and in the subsoil – from 0 to 6 days. The calculated 95% Tukey confidence intervals together with the mean values for both indicators showed high variability of redox resistance within particular soil units, especially in the subsurface layers. Characteristic is elongation time of reduction in the deeper layers. This time is two-fold in the subsurface layers and three-fold longer in the subsoil than that in the surface layers. In order to estimate thermal dependence of redox resistance, t_{300} and t_{400} were measured additionally at temperatures 4, 10, and 15°C in samples of 3-5 selected profiles from each of the soil unit. The data obtained allowed presentation of the percentage of particular t_{400} and t_{300} classes in diagrams (Figs 8, 9).

Based on the estimation of the redox properties expressed by $t_{300,}$ the soils stored in the DPAMS were classified into 4 groups of redox resistance (slight, limited, differentiated, and prolonged) based on the t_{300} values estimated at 4, 10, 15, and 20°C for the three levels (surface, subsurface, and subsoil) of soil profiles (Stępniewska *et al*., 2004). Slight resistance (t_{300} below 4 days) is characteristic of Leptosols, Luvisols and Cambisols formed of loess and part of mountain soils. Limited resistance (t_{300} equal to 4-8 days) characterizes a considerable group of soils, including Fluvisols, Gleysols, mountain soils – heavy loams and clays. Differentiated resistance (t_{300} equal to 8-20 days) is characteristic of Luvisols and Cambisols formed of loamy sands and heavy loams, hydrogenic silts and Terric Histosols. Soils with prolonged resistance (t_{300} more than 20 days and even 50) are Luvisols and Cambisols formed of sands and light loams. The t_{300} values increased with the depth of soil profiles and the differences in the individual layers of the soil profiles were in the range from:

- 8.38 days at 4°C to 2.84 days at 20°C in the surface layers;
- 27.34 days at 4°C to 6.09 days at 20°C in the subsurface layers;
- 32.63 days at 4°C to 8.79 days at 20°C in the subsoil.

The knowledge of soil redox resistance indicators t_{300} and t_{400}, allowed calculation of potential denitrification of soils (*PD*) from the equation (Gliński *et al*., 2000):

$$PD = 10Hd\, C_{NO_3-N} / t_{300} - t_{400}\ (\mathrm{kg\ ha^{-1}\ day^{-1}\ N\text{-}N_2O}),$$

where: C_{NO_3-N} (mg kg soil^{-1}) – the nitrate-nitrogen content, H (m) – soil layer thickness, and d (Mg m^{-3}) – soil bulk density, 10 – results of division of 10 000 m^2 ha^{-1} by 1 000 g kg^{-1}, t_{300}-t_{400} – the nitrate buffer period.

The representative samples of the surface layers of soils gathered in the DPAMS allowed calculation of *PD* for the soil units of the entire territory of Poland and distinguishing 6 groups of *PD* (< 7.5, 7.5-15, 15-30, 30-50, 50-80 and > 80) (Gliński and Ostrowski, 2011; Gliński *et al*., 2000; Stępniewska *et al*., 1997).

Biological (microbiological) properties

Inherent soil physical and chemical properties such as PSD, water retention, the C_{org} content and mineral composition are crucial for soil quality, and create microhabitats for soil biota. Soil microbial communities take part in many important processes, including organic matter decomposition, gas emission and sink, pollutant breakdown, energy flow, and nutrient cycling in the ecosystem (Koper and Brzezińska, 2011; Włodarczyk *et al*., 2002a).

Chosen soils from the DPAMS were assayed for their biological activity. The respiration, denitrification, and methanogenic potentials (CO_2, N_2O, CH_4 production, respectively) were determined using a gas chromatography method (Brzezińska *et al*., 2011a, 2012; Włodarczyk *et al*., 2005; 2011), while dehydrogenase activity was assayed colorimetrically with triphenyltetrazolium chloride, TTC (Brzezińska *et al*., 1998). The activity of soil microbes naturally changes in time and space, depending on such factors as substrate availability, temperature, and air-water conditions (Brzezińska *et al*., 2011b; Walkiewicz *et al*., 2012; Witkowska-Walczak *et al*., 2012). However, when measured under standardized conditions, it expresses the potential of tested soils to perform the given processes. All the biochemical properties mentioned above may be treated as biological indicators, since they were measured in standardized conditions and show the potential of the investigated soil rather than the current conditions in the soil. Soil respiration, which reflects the microbial organic matter mineralization, when measured in standard conditions (20°C, 14 days, pF 1.5) varied between 71.9 and 393.1 mg CO_2-C kg^{-1} (Gliński *et al*., 2010; Walkiewicz *et al*., 2012) (Table 8). Denitrification

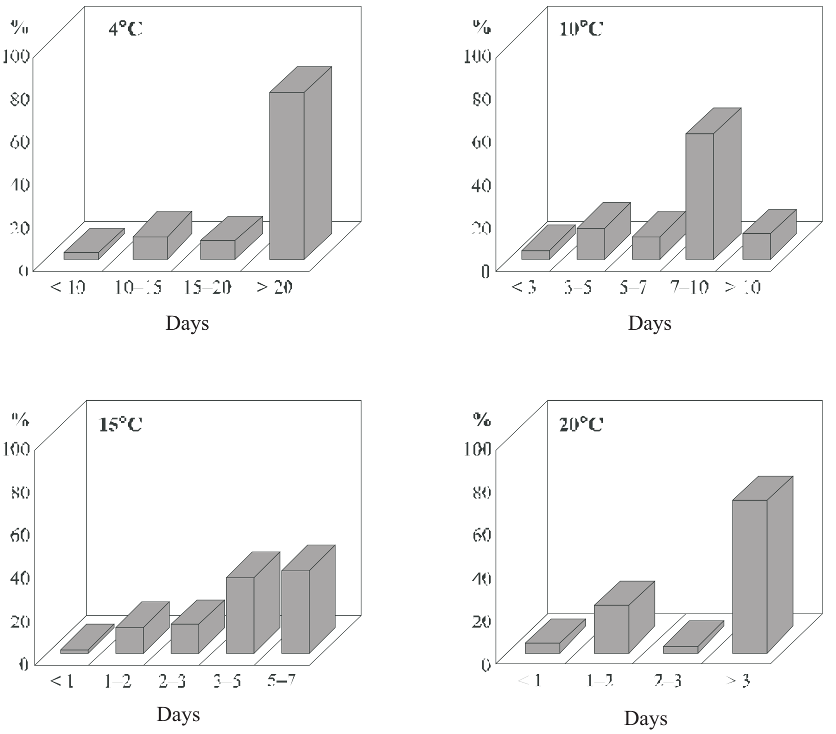

Fig. 8. Percentage of particular t_{300} classes for different temperatures in the total area of soil surface layers (Stępniewska *et al*., 1996-1997).

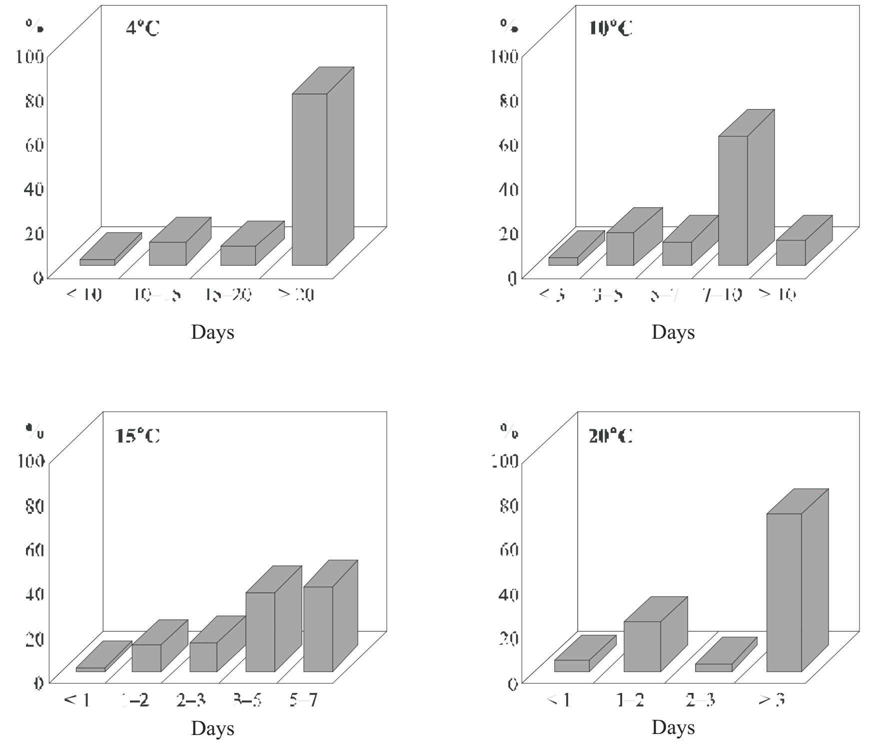

Fig. 9. Percentage of particular t_{400} classes for different temperatures in the total area of soil surface layers (Stępniewska *et al*., 1996-1997).

Table 8. Soil respiration and dehydrogenase activity (14-day incubation at 20°C, pF 1.5), denitrification (24-hours anaerobic incubation at 20°C) and methanogenic potential (77-day anaerobic flood incubation at 25°C). Each value is an average from three replications

Soil type	Respiration mg CO_2-C kg^{-1}	Dehydrogenases µg TPF g^{-1} 20 h^{-1}	Denitrification mg N_2O-N kg^{-1}	Methane production mg CH_4-C kg^{-1}
Cambisols	96.9 - 297.5	7.22 - 108.4	0.10-26.6	3.46 - 279.7
Gleysols	127.5 - 393.1	14.5 - 196.3	9.5-18.8	140.1 - 520.1
Luvisols	132.7 - 237.3	1.81 - 11.2	n.t.	n.t.
Phaeozems	203.4 - 314.2	16.6 - 179.0	8.1-18.5	89.7 - 364.7
Podzols	71.9 - 195.4	1.21 - 4.50	1.5-12.9	3.17 - 193.9

activity, which expresses soil ability of nitrate reduction under anaerobic conditions, was diverse and the N_2O efflux ranged from 0.1-26.6 mg N kg^{-1} depending on the type of soil (Szarlip *et al*., 2010; Włodarczyk, 2002b; Włodarczyk *et al*., 2004). Soil dehydrogenase activity, an index of the total soil microbial activity, varied between 1.21 and 196.3 µg TPF g^{-1} 20 h^{-1} (Brzezińska *et al*., 1998, 2004) (Table 8).

SUMMARY

The many years experience of the use of the database of Polish arable mineral soil (DPAMS) substantiated the development of this database. This project contributed to:

- extending the knowledge from a lot of analytical data (obtained under fixed laboratory conditions) of the hydrophysical, oxidation-reduction, and biological properties and processes occurring in Polish soils;
- development of country-scale maps of hydrophysical and oxidation-reduction properties and the specific surface area, which provide abundant data for prediction of various scenarios of processes occurring in the soil environment;
- a possibility (through precise localization of the soil profiles) for cyclic return to the sampling place at optimal time intervals, which is a basis for soil monitoring.

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