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Spatial characteristic of hydro-physical properties in arable mineral soils in Poland as illustrated by field water capacity (FWC)

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A b s t r a c t. The spatial characteristics of the field water capacity (FWC) of Polish soils have been presented. It was found that their values range from 3.9 to 45.5 %, vol. in relation to soil units and are mostly differentiated by the soil granulometric distribution. Variability of the value of field water capacity in individual regions can be seen in the well delineated belt of the central uplands, foothills and mountain areas; it divides Poland into two structural zones for which the threshold FWC value in the surface layer and subsurface is 25 and 30% in the subsoil.

K e y w o r d s: field water capacity, Polish soils

INTRODUCTION

The hydro-physical properties of soils, i.e., water retention and water permeability 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 agro-technical mechanical treatments applied. A knowledge of the hydro-physical 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 hydro-physical characteristics [1,2,5,13,14,26,31].

Hydro-physical soil properties are difficult to measure and require expensive special measuring equipment. Measuring procedures are also time consuming. Hence, data bases on hydro-physical soil properties are scarce and scattered. These are mainly the results of studies carried out in individual research institutions that are kept there. These results are difficult to interpret due to the various methods of research applied.

The problem of creating a data bank of hydro-physical soil properties is very important and has been undertaken by the research commissions of the European Union. Since it is necessary to assume a common strategy of action in this respect, in 1995 a project to use the existing data to derive hydraulic parameters for the simulation models in the environmental studies and in land-use planning was carried out by 18 research institutes from the European Union member states. The goal behind it was to create a common information data base on the hydro-physical soil characteristics based on the results of measurements carried out in individual countries [1,2,3,7,11,30,31]. In the period 1998-2001 in Poland, in the Institute of Agrophysics of the Polish Academy of Sciences, a research project financed by the State Committee for Scientific Research entitled 'Elaboration of the data base and maps of the hydro-physical properties of the arable soils in Poland' was carried out. The above programme is compatible with the assumptions of the data bank of the hydro-physical properties of soils in the European Union [8,12,17-21,23,24,27-29].

The aim of this study was to present the spatial characteristics of the hydro-physical properties of the mineral arable soils of Poland in the example of water field capacity.

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MATERIALS AND METHODS

Characteristics of the soil material

The assumed aim of the research, i.e., characteristics of the hydro-physical properties of arable soils on the basis of their field water capacity (FWC), called for a representative set of soil profiles in respect of their FWC from the area of the whole of Poland reflecting soil variability and diversity. The solution of the above problem required a sensible compro- mise between the number of the soil profiles studied and samples taken from them that would fulfil statistical criteria, and the financial means that could be assigned for the realisation of the project of creating a bank of soil samples.

Soil division into taxonomic elementary soil units used in the Polish soil systematics is too detailed [15]. For the above reason and also due to economic and organisational reasons, it was decided to collect samples that would allow the characterisation of the more important soils that exert a significant influence on plant breeding conditions and are important for the improvement of arable soils. A thousand representative samples of the soil profiles located in Poland were selected with a view to fulfilling the above condition adequately to the variability and differentiation of the soil cover to be able to evaluate them and present them cartographically on maps in a scale of 1:1 500 000 to 1:2 500 000. Data of the soil cover structure were taken from the numerical presentations collected in the study called 'Agricultural production space of Poland in numbers' [25]. On the basis of the taxonomic division used in the above study, the arable mineral soils were aggregated into 29 groups with similar properties (Table 1). According to the FAO classification they are: Nos 1-2: Rendzinas; No. 3: Phaeozems; Nos 4-19: Cambisols, Luvisols and Podzols, Nos 20-22: Fluvisols, Nos 23-24: Gleysols and No. 25: Histosols. The aggregated soil groups are characterised by a differentiated area of their appearance in Poland ranging from 380 km^2 to 40 980 km^2. Due to the above consideration, it was necessary to establish the number of profiles to represent each of the aggregated groups so that the appropriate proportions were observed. The studies carried out in the Institute of Agrophysics of the Polish Academy of Sciences showed that the minimum number of samples in one population was 20, since with this amount of profiles the coefficient of variability of the more important properties of the selected soil units under studies became stabilised. Hence it was assumed that this number of profiles would represent the soils whose surface contribution did not exceed the medium value for one soil unit. Two soil profiles were added to the above number to safeguard against any unforeseen events such as damage to the samples, mistakes in soil identification. Further to the criteria assumed that way, the selected soil units were represented by 726 profiles. The remaining 274 profiles were divided proportionally among the soil units with the surface area on which they appear exceeding the calculated medium value.

The next step was to solve the problem of localisation of the soil profiles studied. This required a knowledge of basic attributes such as:

- cartographic mapping of the soil cover structure in the form of a soil map,
- surface representation of the soil units in the structure of the soil cover of Poland.

The analysis carried out showed that the only available source of information for working out the location lay-out of the soil profiles studied, was the study entitled 'Agricultural production space in Poland presented in numbers' [25]. It included a surface structure of the aggregated soil groups according to the complexes of agricultural usability in the areas of individual districts (according to the administrative division of Poland before 1975). Hence, the structure of the spatial distribution of the profiles studied was created from the indications of which soil units samples should be taken from individual districts, and the number of profiles which should represent them. Further localisation of the soil profiles studied on the background of the soil cover was done on the basis of a soil - agricultural map or a soil map in the scale of 1:1 500 000 and 1:300 000. Due to the morphological diversity of the soil profile structures and differentiated sequences of soil levels, their cartographic presentation of properties was based on the division of the soil profile into three levels for the sake of uniformity in the method of map preparation:

- a level defined as a surface level referring to the arable - humus level;
- a level defined as a subsurface level (sub-arable) that can be distinguished by the predominance of the mineralisation processes of the organic matter which gets into it;
- a level defined as subsoil, with predominating natural features of the mineral soil substrate. Following the above methodological assumptions, field experiments were carried out and documented with:

– the location of the soil profile studied on the topographical map;
– morphological description of the soil features;
– soil samples with undisturbed structure taken to cylinders with a capacity of 100 cm^3 and a height of 5 cm from the more significant diagnostic levels in the surface layer (arable), subsurface layer (sub-arable) and from the subsoil.

The documentation and soil material so-obtained was then used for setting up a bank of soil samples [4]. Two hundred-and-ninety profiles were then chosen out from the soil samples collected in the bank. The profiles chosen represented generalised soil units that were subjected to the testing of hydro-physical soil properties, in particular field water capacity [21,22].

T a b l e 1. Parametrisation of the field water capacity for generalized soil units

	Generalized soil units	Field water capacity in value intervals (% cm^3cm^{-3})		
		Surface layer	Subsurface layer	Subsoil
	1	2	3	4
1.	Rendzinas pure	30 - 35	35 - 40	40 - 45
2.	Rendzinas mixed	20 - 25	30 - 35	30 - 35
3.	Chernozems	30 - 35	30 - 35	30 - 35
4.	Brown, rusty and podzolic soils derived from weakly loamy sands and loose sands	10 - 15	5 - 10	5 - 10
5.	Brown, rusty and podzolic soils derived from weakly loamy sands and light loamy sands	15 - 20	10 - 15	10 - 15
6.	Brown and pseudopodzolic soils derived from loamy sands	20 - 25	20 - 25	5 - 10
7a.	Brown soils derived from loamy sands lying on heavier substrate	15 - 20	15 - 20	20 - 25
7b.	Pseudopodzolic soils derived from loamy sands lying on heavier substrate	20 - 25	15 - 20	25 - 30
8a.	Brown soils derived from light loam	20 - 25	15 - 20	25 - 30
8b.	Pseudopodzolic soils derived from light loam	20 - 25	15 - 20	20 - 25
9a.	Brown soils derived from medium loam	20 - 25	25 - 30	25 - 30
9b.	Pseudopodzolic soils derived from medium loam	20 - 25	25 - 30	25 - 30
10.	Brown and pseudopodzolic soils derived from heavy loam	25 - 30	35 - 40	30 - 35
11.	Brown and pseudopodzolic soils derived from shallow loam on light substrate	20 - 25	25 - 30	5 - 10
12.	Brown and pseudopodzolic soils derived from gravel	10 - 15	5 - 10	<5
13a.	Brown soils derived from silts of water origin	25 - 30	20 - 25	15 - 20
13b.	Pseudopodzolic soils derived from silts of water origin	30 - 35	25 - 30	25 - 30
14.	Brown and pseudopodzolic soils derived from loess and loesslike materials	30 - 35	30 - 35	35 - 40
15.	Brown and pseudopodzolic soils derived from clays	35 - 40	45 - 50	45 - 50
16.	Brown and pseudopodzolic soils derived from lithic rocks - loamy and skeleton-loamy	30 - 35	30 - 35	30 - 35
17.	Brown and pseudopodzolic soils derived from lithic rocks - loamy	30 - 35	35 - 40	35 - 40
18.	Brown and pseudopodzolic soils derived from lithic rocks - clayey	35 - 40	35 - 40	35 - 40
19.	Brown and pseudopodzolic soils derived from lithic rocks - silty	35 - 40	30 - 35	35 - 40
20.	Heavy alluvial soils	35 - 40	35 - 40	35 - 40
21.	Light and very light alluvial soils	20 - 25	15 - 20	10 - 15
22.	Light and medium alluvial soils	30 - 35	30 - 35	35 - 40
23.	Black earth	25 - 30	25 - 30	25 - 30
24.	Black earth derived from sands	20 - 25	10 - 15	5 - 10
25.	Mursh and murshy soils	20 - 25	10 - 15	5 - 10

Measuring methods

The measurements of static hydro-physical characteristics of the arable mineral soils of Poland, i.e., relation between soil water potential and water content, were taken within the range from 0.1 kJ m^{-3} (pF 0) to 1 500 kJ m^{-3} (pF 4.2) for the eleven points in the process of drying, using standard pressure chambers manufactured by Soil Moisture, Santa Barbara, California USA, following the method by Richards [6]. It was assumed that the field water capacity in the conditions in Poland represents the water content which is bound in the soil with a potential of 16 kJ m^{-3} (pF 2.2) [16,26]. Water content of the soils was expressed in the volumetric units (% m^3 m^{-3}) as they take into consideration soil compaction and allow for the balance calculation of water resources.

RESULTS

Characteristics of the field water capacity of Polish arable soils

The values obtained for field water capacity in soil samples belonging to individual soil units were subordinated to five-percent intervals relating to the three soil layers studied (Table 1, column 1) [21]. Such a subordination of study results help to carry out comparative analysis of the property studies both in relation to the FWC value and the recognition of factors conditioning its variability and differentiation. The above analysis showed that the FWC levels of arable soils showed considerable differentiation in relation to the soil units ranging from 3.9 to 45.5% (the minimum value - subsoil of soil No. 12, the maximum value - subsurface layer of soil No. 15) and considerably lower differentiation in the 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 was up to 20%.

The analysis carried out showed also that the differentiation and variability of FWC was formed by four factors: granulometric distribution and its uniformity in the soil profile, type of soil formation and humus content. The FWC values are differentiated to the highest degree by the granulometric distribution. An obvious confirmation of the above conclusion are the FWC values of the gravel (>5 - 15%) and clay (35-50%) soils as well as the soils with a differentiated texture in the soil profile such as brown soils derived from light loam (15-30%) as compared to the soils with a uniform granulometric distribution, e.g., chernozems derived from loess (30-35%). FWC differentiated also the origin of matric formations quite clearly. Soil was formed from silt (loess, silt of water origin and weathering silt of mountain soils). In the above soils, differences in the FWC differentiation in the soil profile can be observed; the soils formed from loess showed a relatively uniform FWC in the soil profile whereas in the soils formed from silt of water origin, FWC decreases with the depth of soil profile, and in the weathering soils it increases. The skeleton content influenced FWC negatively which could be seen in the comparison of FWC in the subsurface and subsoil of the loamy and skeleton-loamy mountain soils. The influence of the humus content was expressed in the narrowing of the FWC differentiation in the surface layers and its increased values in relation to the deeper layers. With a limited differentiation of the granulometric distribution FWC of the surface layer ranged from 12.1 to 37.8%, whereas in the subsoil it was 3.9 -45.1%. At the same time, the soils with higher humus content, e.g., light black earths, had higher FWC values in their surface layer than the brown soils of similar granulometric distribution. The above tendency was confirmed also by a comparison of FWC of the surface layer of mixed rendzinas and brown soils originating from loamy sands. However, it disappears in the case of soils derived from loess (chernozems and brown soils). It may be due to the fact that the differences in the humus content in the surface layer of these soils were not too large.

The analysis of the absolute FWC values suggested a division of the arable soils into three groups, i.e.:

- soils with low FWC values (up to 20%),
- soils with medium FWC values (20-30%),
- soils with high FWC values (above 30%).

In the group with the lowest FWC values there are soils formed from sand, gravel, light and very light alluvial soils. The group with the highest FWC included pure rendzinas, chernozems, medium and heavy alluvial soils, loess and loamy brown soils, and weathering soils (mountain soils). The remaining soils, mainly formed of post-glacial formations, belonged to soils with medium retention abilities.

Cartographic presentation of variability and differentiation in the field water capacity

Variability and differentiation of the FWC levels of arable soils have been presented in the maps (Figs 1, 2, and 3), for the surface, subsurface and subsoil layers, respectively. The maps were plotted using computer technology by combining the results of the FWC measurements with the content of the arable land map on a scale of 1: 1 000 000 and digitally recorded in the Soil - Cartographic Data Base [9,10]. The base consists of a set of files containing the contents of the soil map and the software necessary for the storing and creating of various sorts of derivative maps relating to the soil cover. The basic file contains a map of soil units distribution. The main function of the processing system is grouping the maps into appropriate classes, and then applying an identical colour to the contours of all soils belonging to this class. As a result, a colourful topical map showing class distribution is created. In the mathematical approach, the solution consists in a topological connection of soil contours into

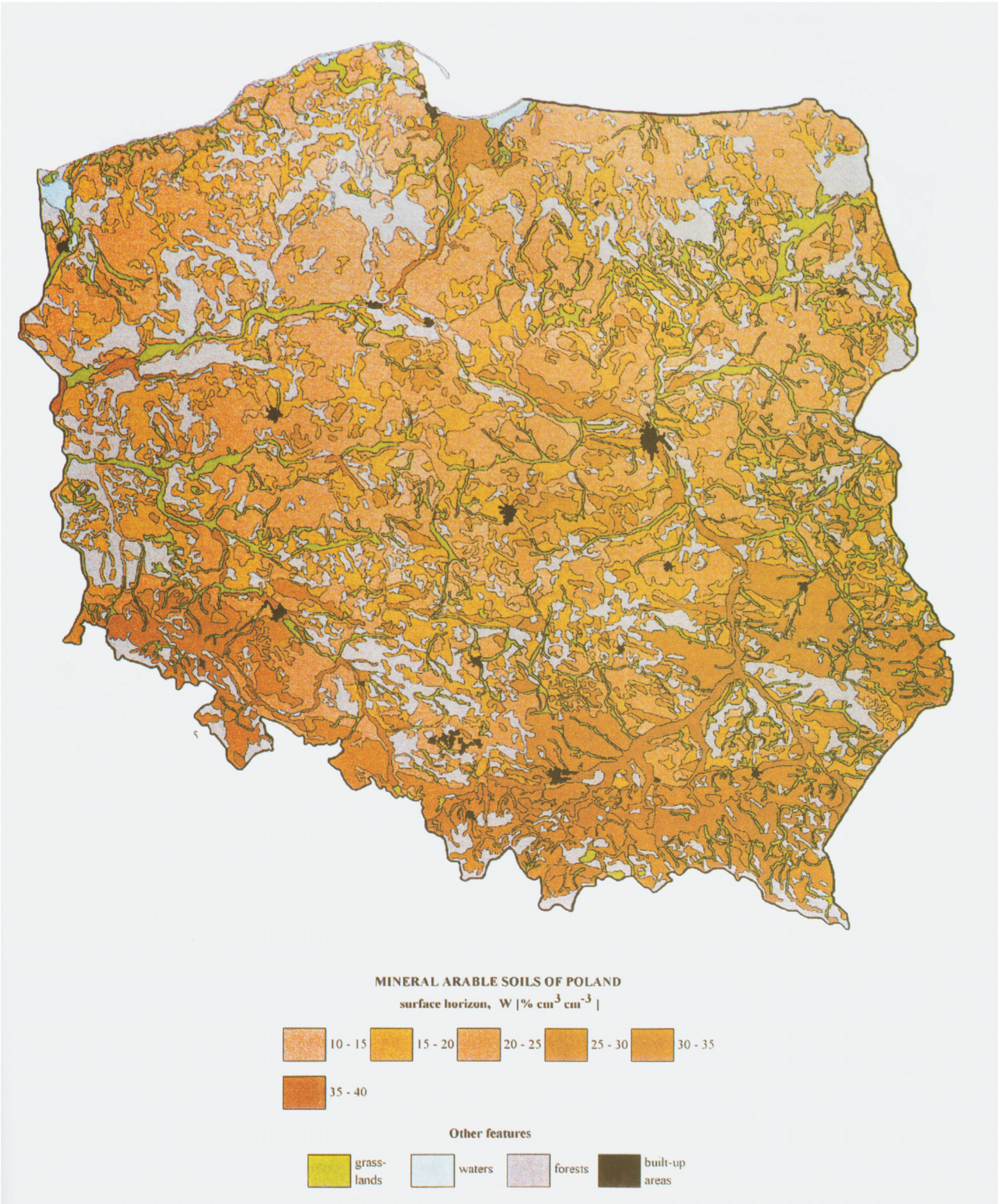

Fig. 1. Map of water retention at field water capacity (pF 2.2) of soil surface layers.

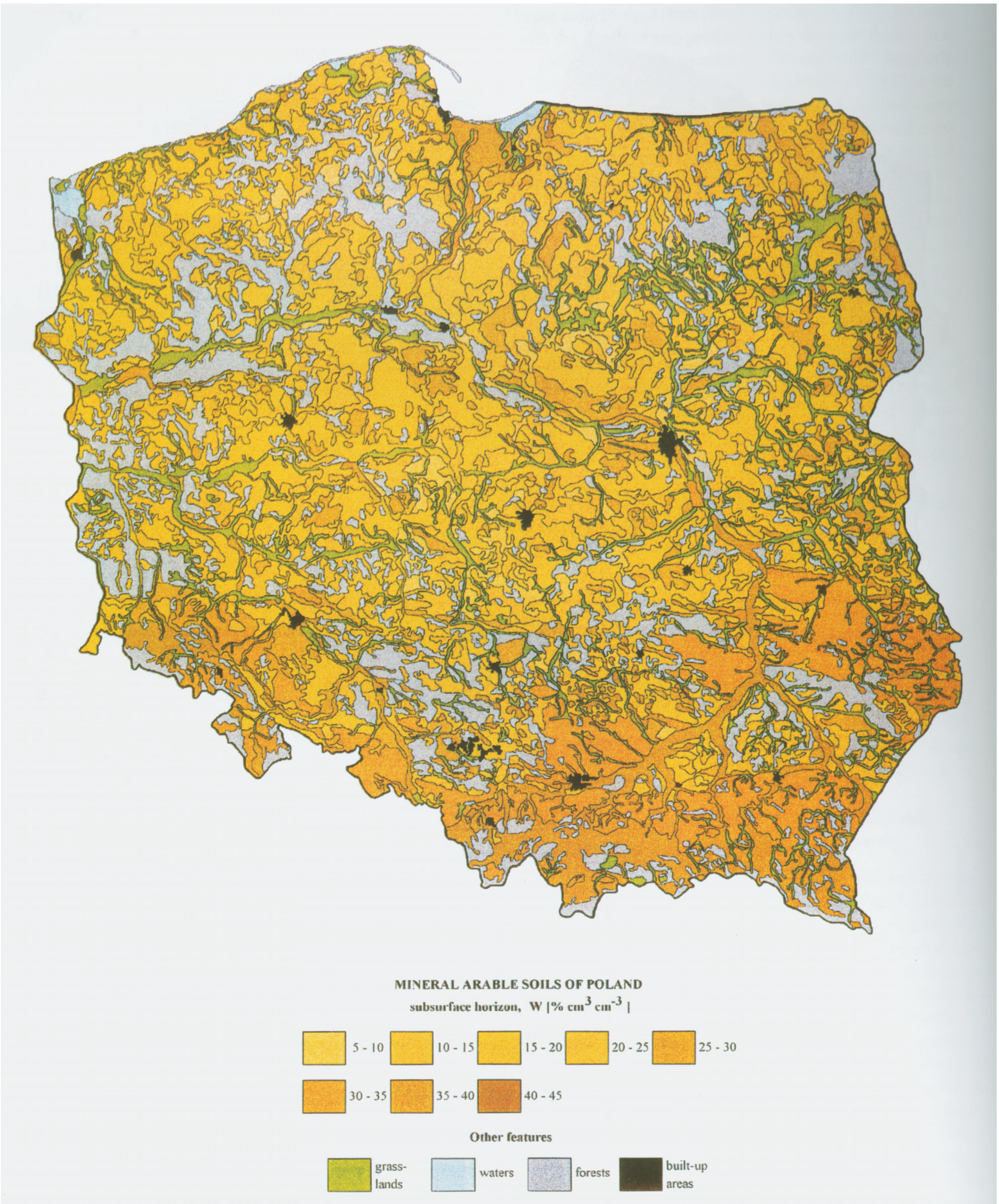

Fig. 2. Map of water retention at field water capacity (pF 2.2) of soil subsurface layers.

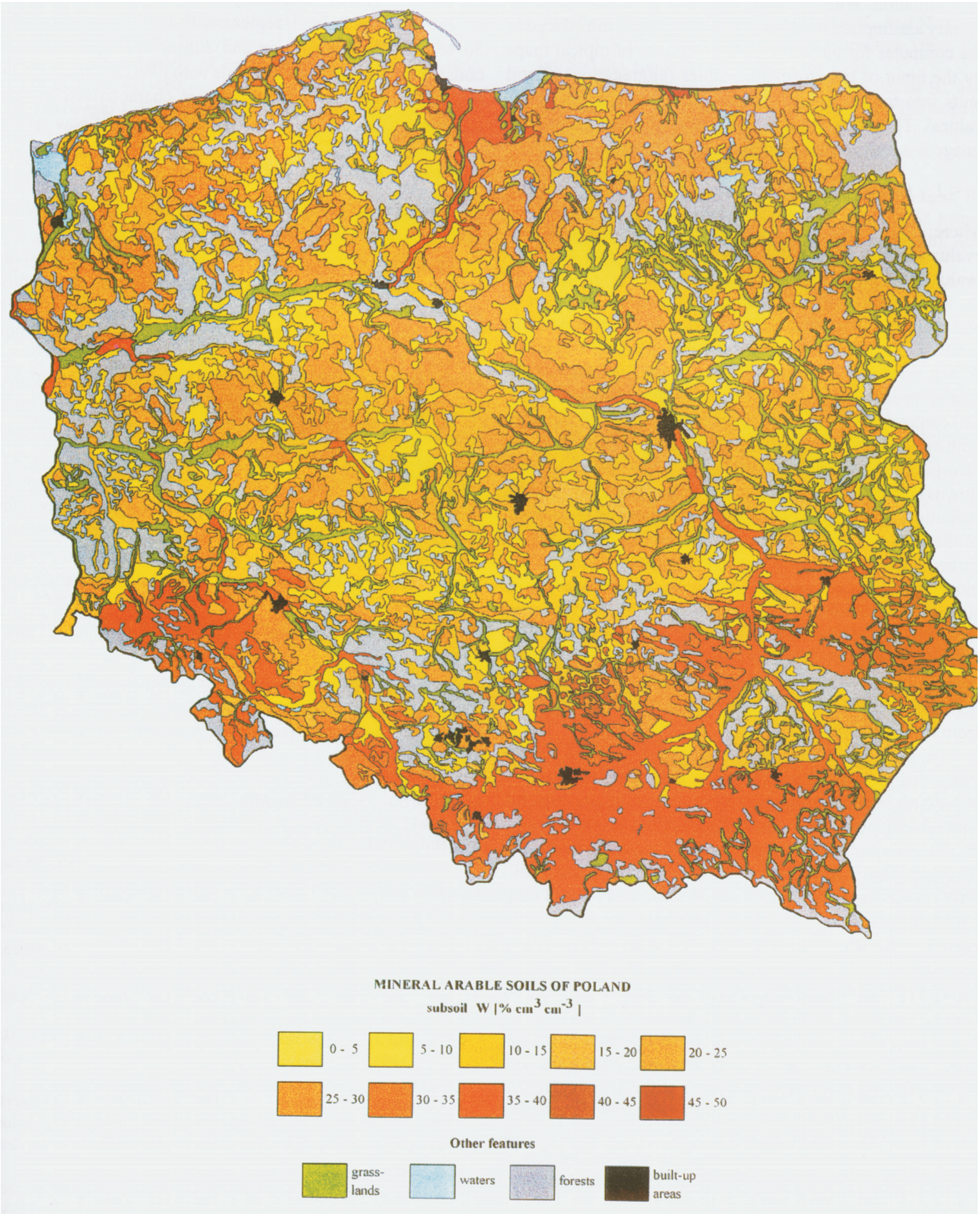

Fig. 3. Map of water retention at field water capacity (pF 2.2) of subsoil layers.

one topical contour according to the assumed function of subordination. When working out the topical maps, a preliminary assumption was that a soil map will be introduced to the computer for the automatic generation of topical maps by the input of transformation tables (aggregation) of soil units into topical units (expressed as, for example, FWC values). The basis for the 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.

Due to the character of the generalisation of results, it was established that the FWC maps would be generated on a scale of 1:2 500 000 so that they can be sized to an A-3 format ensuring appropriate clarity and legibility of the spatial structure of soil feature carted. It was assumed that soil contours with a determined property would be signalled with a colouring into which other forms of land use would be incorporated, i.e., valley grassland, larger housing areas (towns), forests and inland water reservoirs. Since the distribution of the above elements, supplementing the content of the map, gives sufficient information on the spatial location on the country scale, no topographic content was introduced into the maps of hydro-physical soil properties such as roads, river nets, names of towns so as not to disrupt legibility and clarity of their content or diminish their informative value. The contours shown in the colourful maps group mean FWC values within the classes of the property determined preserving also individual deviations resulting from detailed studies.

Analysis of the maps enclosed, clearly showed that the most visible variability of FWC in individual regions was expressed in the clearly separated belt of central upland, foothill and mountain areas. It divides Poland into two structural zones for which the threshold FWC value in the surface and subsurface layer is 25 and 30% in the subsoil. FWC values lower than 25% are predominant in the Polish Lowland and in the northern moraine regions. Areas in the region of the Vistulian Żuławy, Płock and Błońsko-Sochaczew Plain, and Kujawy, where the FWC value, especially in the surface layer, did not exceed 30%. In the remaining soil layers, high FWC values were observed only in the Vistulian Żuławy. The FWC values of the soils in the uplands and mountain regions of Poland were even more uniform with a clear decrease in the soils of the lower part of the San and Wisłoka river basins and in the Kraków-Częstochowa Jura, and the highest values in the Vistula valley and Karpaty Mountains. High FWC values with little differentiation in the subsoil were characteristic for the southern regions.

In the area of the Polish Lowland and northern uplands, areas with the soils where the FWC in the surface layer were from 20 to 25% and in the subsurface layer form 15 to 25% were predominant. The subsoil of these regions showed very varied FCW values without any clearly visible dominants.

In southern Poland, regions with the FWC value from 30 to 35% in the surface and subsurface layers with a considerable contribution of soils with FWC in the range 35 -40%. The subsoil of these soils is characterised by the dominant FWC values in a range from 35 to 40%.

CONCLUSIONS

On the basis of the present studies and maps constructed on their basis, it is possible to determine that:

1. Field water capacity (FWC) of the arable Polish soils shows a considerable differentiation in relation to soil units ranging from 3.9 to 45.5%; differentiation of the soil profiles in the individual soil units is much lower and does not exceed 10%.

2. The value of the FWC of the Polish soils is mostly differentiated by the granulometric distribution, whereas features such as matric formation, skeleton content and humus exert less influence.

3. The lowest FWC values were observed in the soils derived from sand and gravel, as well as light and very light alluvial soils, and the highest in the pure rendzinas and chernozems, medium heavy and heavy alluvial soils, and brown soils derived from loess and clays and weathering (mountain) soils.

4. The most important variability of FWC in individual regions was expressed by the separated belt of central uplands, foothill and mountain regions; it divides Poland into two structural zones for which the threshold value of FWC is 25% in the surface and subsurface level and 30% in the subsoil.

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