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Spatial characteristics of potentially useful retention in Polish arable soils

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A b s t r a c t. The spatial characteristics of potentially useful retention (PUR) in Polish arable soils have been presented. It was found that the values ranged from 2.1 to 27.2% vol. in relation to soil units. The highest differentiation of PUR occurred in the subsoil, and the lowest in the arable soil layer. Poland can be divided into two structural units with respect to potentially useful retention. The first of them includes Highlands, Foothills and the Karpaty and the Sudety Mountains where the highest PUR values are predominant; and the second – the Polish Lowlands and Lake Districts, which are characterised by medium PUR values.

K e y w o r d s: Polish arable soils, potentially useful retention

INTRODUCTION

Water plays a crucial role in the processes of plant growth, which involves cell division and cell expansion [5]. The latter process occurs as each pair of divided cell imbibes water. The resulting internal pressure, called turgor, stretches the elastic walls of the new cells, which thicken on account of the deposition of newly synthesized material. Plants can take water up from the soil by their root systems. Various terms used to characterise the state of water in different parts of the soil-plant-atmosphere system are merely alternative expressions of the energy level or potential of water. In order to describe the interlinked processes of water transport throughout the soil-plant-atmosphere continuum, one should evaluate the pertinent components of water energy potential and their effective gradients as they vary in space and time [8,10].

The hydro-physical soil properties not only shape soil water balance but are also decisive for the conditions of plant growth, development and yield. They also determine water availability for the plant root system and water transfer with chemical compounds dissolved in it into deeper soil layers. The above compounds are nutrients indispensable for plant growth and all kinds of other chemical substances, which pose a threat to the environment [1,2,7,13,16]. Hence, research on the amount of water available for plants which determines their growth and development and at the same time influences yield is carried out in many countries of the world [3,4,9,14,18–25,27–30].

The purpose of this study was to present the spatial characteristic of potentially useful retention in the Polish arable soils.

MATERIALS AND METHODS

Characteristics of the soils

The assumed aim of the research, i.e., characteristics of the hydro-physical properties of arable soils on the basis of their potentially useful retention (PUR), called for a representative set of soil profiles in respect of their PUR from the whole of Poland reflecting soil variability and diversity. 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 exerting a significant influence on plant production conditions and important for the improvement of arable soils. A thousand representative samples of soil profiles located in Poland were selected with a view to fulfilling the above conditions adequately to the variability and differentiation of the soil cover for their evaluation and cartographic presentation on maps in a scale of 1:1 500 000 to 1:2 500 000. Data of the soil cover structure was taken from the numerical presentations collected in the

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study entitled 'An agricultural productive space of Poland by numbers' [26]. On the basis of the taxonomic division used in the above study, the arable mineral soils were aggregated into groups with similar properties (Table 1) [12]. According 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 occurrence in Poland ranging from 380 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

T a b l e 1. Parametrisation of the potentially useful retention (PUR) for generalized soil units

Generalized soil units		Potentially useful retention in value intervals (%, cm^3 cm^{-3})		
		Surface layer	Subsurface layer	Subsoil
1		2	3	4
1.	Rendzinas (pure)	9–12	12–15	9–12
2.	Rendzinas (mixed)	12–15	12–15	21–24
3.	Chernozems	24–27	24–27	27–30
4.	Brown, rusty and podzolic soils derived from weakly loamy sands and loose sands	6–9	6–9	3–6
5.	Brown, rusty and podzolic soils derived from weakly loamy sands and light loamy sands	12–15	10–12	9–12
6.	Brown and pseudopodzolic soils derived from loamy sands	15–18	15–18	3–6
7a.	Brown soils derived from loamy sands lying on heavier substrate	12–15	12–15	9–12
7b.	Pseudopodzolic soils derived from loamy sands lying on heavier substrate	12–15	15–18	12–15
8a.	Brown soils derived from light loam	12–15	6–9	12–15
8b	Pseudopodzolic soils derived from light loam	12–15	12–15	9–12
9a.	Brown soils derived from medium loam	12–15	15–18	9–12
9b.	Pseudopodzolic soils derived from medium loam	15–18	15–18	12–15
10.	Brown and pseudopodzolic soils derived from heavy loam	12–15	12–15	9–12
11.	Brown and pseudopodzolic soils derived from shallow loam on light substrate	15–18	15–18	3–6
12.	Brown and pseudopodzolic soils derived from gravel	6–9	3–6	0–3
13.a	Brown soils derived from silts of water origin	18–21	15–18	12–15
13b.	Pseudopodzolic soils derived from silts of water origin	24–27	18–21	15–18
14.	Brown and pseudopodzolic soils derived from loess and loesslike materials	24–27	21–24	27–30
15.	Brown and pseudopodzolic soils derived from clays	15–18	12–15	12–15
16.	Brown and pseudopodzolic soils derived from lithic rocks - loamy and skeleton-loamy	15–18	12–15	9–12
17.	Brown and pseudopodzolic soils derived from lithic rocks - loamy	18–21	15–18	21–24

T a b l e 1. Continuation

Generalized soil units		Potentially useful retention in value intervals (%, $cm^3 cm^{-3}$)		
		Surface layer	Subsurface layer	Subsoil
1		2	3	4
18.	Brown and pseudopodzolic soils derived from lithic rocks - clayey	15–18	15–18	12–15
19.	Brown and pseudopodzolic soils derived from lithic rocks - silty	21–24	18–21	15–18
20.	Heavy alluvial soils	15–18	12–15	15–18
21.	Light and very light alluvial soils	15–18	12–15	9–12
22.	Light and medium alluvial soils	18–21	21–24	18–21
23.	Black earth	15–18	12–15	12–15
24.	Black earth derived from sands	15–18	9–12	3–6
25.	Moorsh soils	15–18	6–9	6–9

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 the variability of the more important properties of the selected soil units under studies became stabilised.

The next step was to solve the problem of localisation of the soil profiles studied. This required knowledge of some 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 layout of the soil profiles studied is Witek's elaboration [26]. 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 unit 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 on a 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,
- 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,
- level defined as subsoil, with predominating natural features of the mineral soil substrate.

The soil samples with undisturbed structure were collected into 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 [6]. Two hundred-and-ninety profiles were then chosen 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 potentially useful retention (PUR) which is a measure of soil ability for the retention of water available for plants [21–25, 27–29]. The potentially useful retention (PUR) is also called available moisture range (AMR) or available moisture percentage (AMP).

Measuring methods

The measurements of static hydro-physical characteristics of arable mineral soils of Poland, i.e., the 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. Standard pressure chambers, manufactured by Soil Moisture, Santa Barbara, California USA, were used. It was assumed that the amount of water available for plants called potentially useful retention (PUR) in Polish conditions represents the water content bound in the soil with a potential from 16 kJ m^{-3} (pF 2.2) to 1500 kJ m^{-3} (pF 4.2) [8,11]. Potentially useful retention (PUR) of the soil was expressed in the volumetric units (% m^3 m^{-3}) since it takes into consideration soil compaction and allows a balanced calculation of water resources.

RESULTS

Characteristics of potentially useful retention (PUR) in the arable soils of Poland

The values of potentially useful retention (PUR) obtained for the soil samples from individual soil units were subordinated to three percent intervals (Table 1). A comparative analysis of the results obtained showed that the terminal PUR values, i.e., 2.1% for the sub-soil of the brown soils derived from gravel and 27.2% for the sub-soil of chernozems differed 13 times. However, PUR values for most of the soil units with regard to individual layers ranged from 12 to 15% and from 15 to 18%. The lowest PUR values of 0–3, 3–6 and 6–9% occurred in soils derived from sand and gravel; soils derived from clay and clayey silts had medium PUR values and the highest PUR values from the intervals of 18–21, 21–24, 24–27 and 27–30% were observed in soils derived from silt. Where soils were formed from silt of water origin, the PUR values in the deeper layers decreased, and in soils derived from eolic silt, the same values increased. The relation between the PUR value and the humus content was only generally confirmed. The content of potentially useful water in the rendzinas, which are reach in organic matter, was lower than in other soils with similar granulometric distribution, which may point to the fact that the mineral soil composition can be of greater importance for the formation of water retention abilities by the soil. When analysing potentially useful retention (PUR) in individual soil layers we came to the conclusion that the highest differentiation in this respect was found in the subsoil and the lowest in the arable layer. PUR differentiation in the soil profile depends to a high degree on the contrasting properties of the granulometric distribution of its individual parts. It has been confirmed by studies on brown soils derived from clay underlined with sand in which water retention abilities in the deepest layer (sand) is three times higher than in the arable layer (clay).

Arable soil profiles can be divided into three groups for the general determination of their characteristic values of potentially useful retention generally for the whole profile:

– 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 weak clayey sand and loose gravels. The third group includes soils derived from silts and loesses. The remaining soils are characterised by medium water resources of water available for plants and are predominant in the country.

Cartographic presentation of variability and differentiation of water resources available for plants

The variability and differentiation in the amount of water available for plants called potentially useful retention (PUR) of the arable soils in Poland has been presented in maps of water retention ability (Figs 1–3), respectively for the surface, subsurface and subsoil. The maps were prepared by means of computer technology by combining the values of potentially useful retention with the content of the arable soils map on a scale of 1:1 000 000 which is part of a digital soil-cartographic data base [12,21,22]. The analysis of maps showed that the highest variability of the PUR values appeared in the subsurface layer of the Polish soils and the lowest in the surface layer of these soils. The subsoil, on the other hand, is characterised by the highest differentiation of the PUR values.

The cartographic presentation of the potentially useful retention reflects the division of Poland into two spatial structural units. One is more differentiated and includes the belt of highlands, foothills and mountain areas with the highest PUR values clearly dominating, especially those visible in the surface layer and in the subsoil. The other, less differentiated, includes the regions of the Polish lowlands and lake districts where soils with medium PUR values are predominant with a clear modal PUR value in the 12–15% range in the surface layer.

Such a clear structural differentiation of the spatial variability in the PUR values among the soil layers studied proved that besides the origin of the parent material, both the variability of the soil-formation processes and soil differentiation influenced the formation of potentially useful retention values which was clearly visible in the cartographic reflection of the PUR values in the subsoil layer.

CONCLUSIONS

On the basis of the studies presented and maps constructed on their basis, the following can be concluded:

– potentially useful retention (PUR) of arable Polish soils ranged from 2.1 to 27.2% m^3 m^{-3},
– most of the arable soils of Poland is characterised by values of potentially useful retention (PUR) between 12 and 18% m^3 m^{-3},
– the highest differentiation of potentially useful retention (PUR) was observed in the subsoil, and the lowest in the surface layer of the arable Polish soils,
– the cartographic presentation of the values of potentially useful retention (PUR) divides Poland into two spatial structural units; the first, very differentiated unit, covers

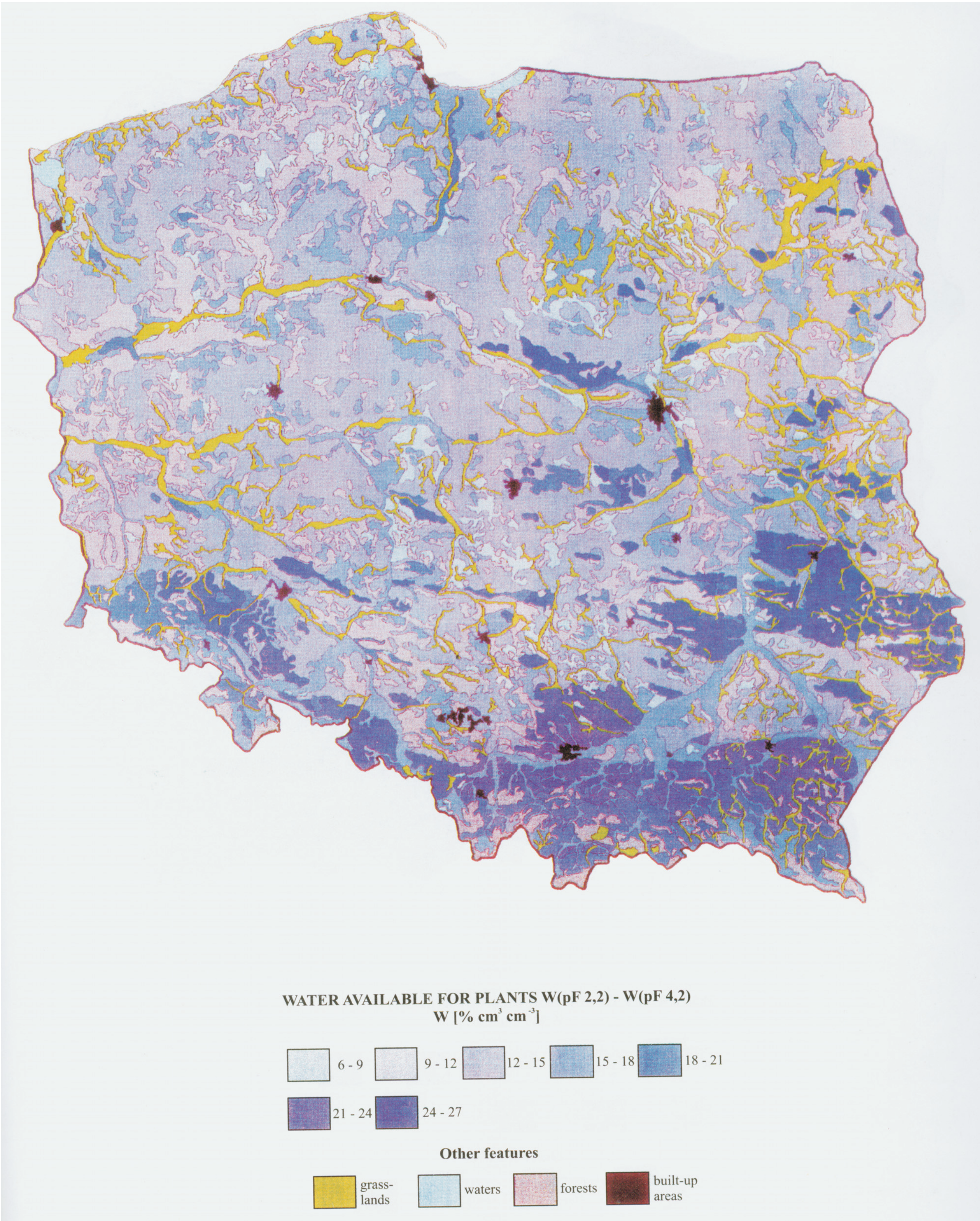

Fig. 1. Map of water retention ability for mineral arable soils of Poland (surface horizon).

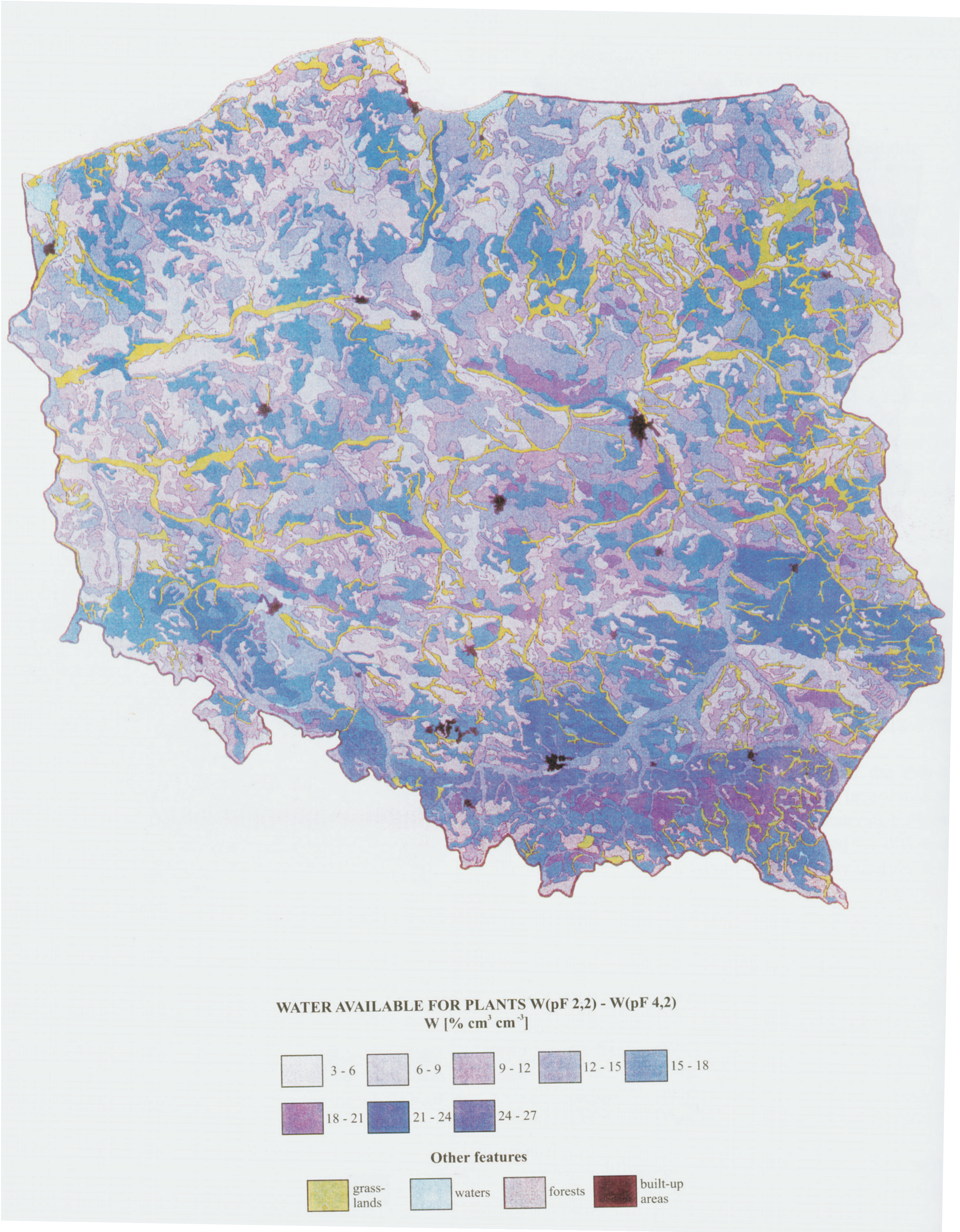

Fig. 2. Map of water retention ability for mineral arable soils of Poland (subsurface horizon).

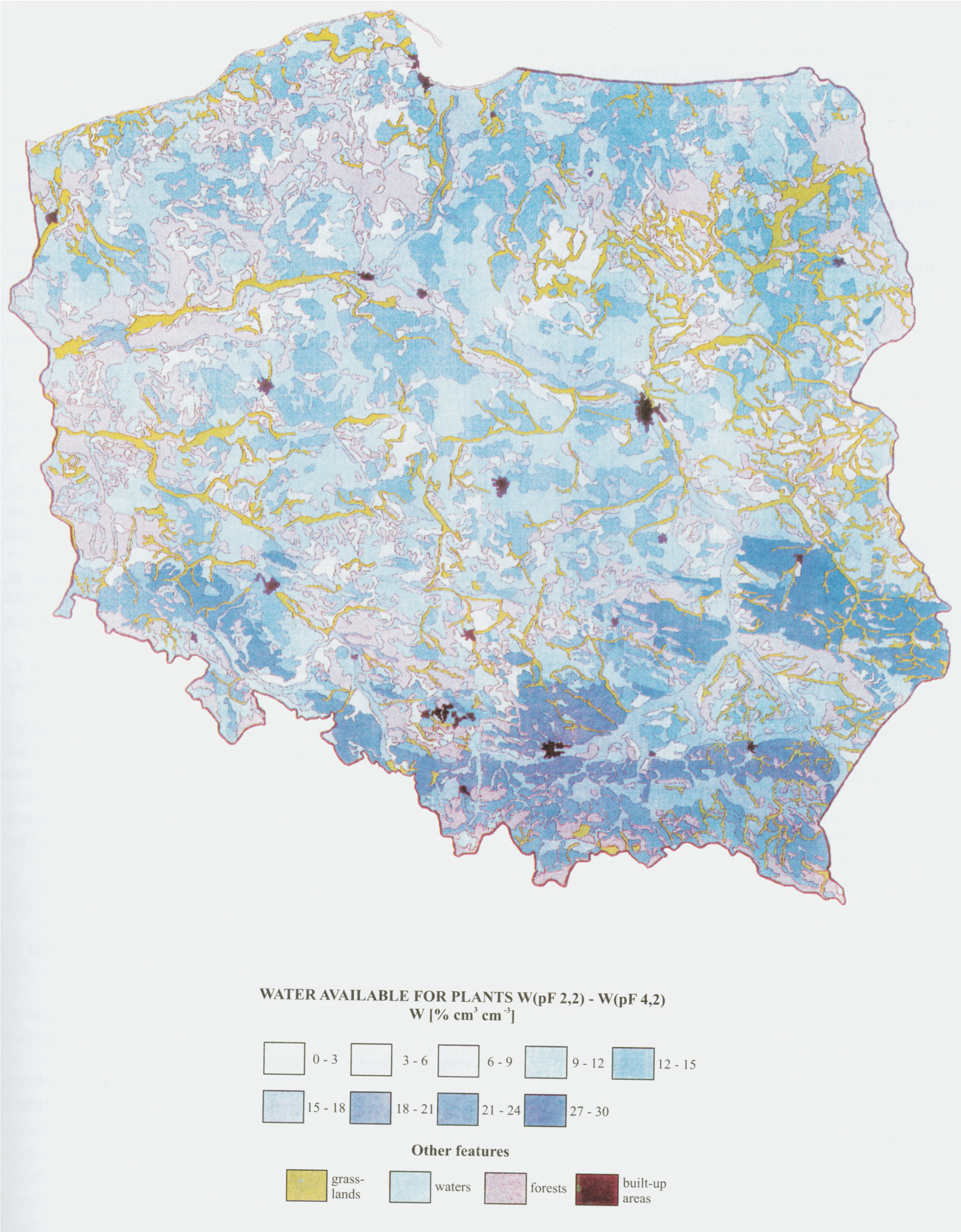

Fig. 3. Map of water retention ability for mineral arable soils of Poland (subsoil).

highland, foothills and the Karpaty and Sudety Mountains, is characterised by the predominance of the highest PUR values; the other, less varied, covers the Polish Lowlands and Lake Districts and is characterised by the predominance of the soils with medium PUR values.

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