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# Pore size distribution and amount of water available for plants in arable soils of Poland

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A b s t r a c t. The results of investigations on porosity and the amount of water available for plants in Polish soils are presented. The porosity and distribution of soil pores are strongly connected with the differentiation of the granulometric composition of Polish soils. The maximum of macropores is in the surface layer whereas the maximum of micropores is in the subsoil. The amount of water available for plants is relatively large, but the amount of water easily available for plants is very small and does not exceed 9%, v/v.

K e y w o r d s: porosity, water available for plants, soils of Poland

## INTRODUCTION

The air and water regimes of soils not only determine soil/water balance but are also decisive for the conditions of plant growth, development and yield. They also influence water availability for a plant's root system and the transfer of water with the 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, 6, 8, 9]. Hence, investigations on porosity and 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, 5, 7, 12–16, 19, 21].

The aim of this study was to show the varying porosity and amounts of water available for plants in arable Polish soils.

## MATERIALS AND METHODS

### Characteristics of the soils

The assumed purpose of the investigations, i.e., the varying porosity and amount of water available for plants of arable Polish soils was reached on the basis of their water potential-moisture characteristics for a representative set of soil profiles throughout Poland, reflecting soil variability and diversity. Soil division into taxonomic elementary soil units, used in the Polish soil system, is too detailed [11]. For the above reason and also for economic and organisational reasons, it was decided to collect samples that would allow soils to be categorized; this is important because of their significant influence on the conditions for plant production and the improvement of arable soils. 290 representative samples of soil profiles located in Poland, were selected; these adequately fulfilled the above conditions of variability and differentiation of the soil cover so that they could be evaluated and cartographically presented in a scale of 1:1 500 000 to 1:2 500 000. The data of the soil cover structure was taken from the numerical presentation, assembled in the study entitled 'The agricultural productive space of Poland by number' [18]. On the basis of the taxonomic division used in the above study, arable mineral soils were arranged into 25 groups, each of them representing soils having similar properties (Table 1) [4]. 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: Mollic Gleysols and No. 25: Histi-Mollic Gleysols. The soil groups collected are categorized by the different areas in Poland in which they occur and these range from 380 km$^2$ to 40 980 km$^2$.

The next step was to place, geographically, 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.

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**T a b l e 1.** Surface area of the generalized soil units in Poland [4]

| No. Genaralized soil unit | Surface area in | |
|---|---|---|
| | $x10^3$ ha | % |
| 1. Rendzinas (pure) | 190 | 1.2 |
| 2. Rendzinas (mixed) | 45 | 0.3 |
| 3. Chernozems | 236 | 1.5 |
| 4. Brown, rusty and podzolic soils derived from weakly loamy sands and loose sands | 4 098 | 27.0 |
| 5. Brown, rusty and podzolic soils derived from weakly loamy sands and light loamy sands | 163 | 11 |
| 6. Brown and pseudopodzolic soils derived from loamy sands | 605 | 4.0 |
| 7. Brown and pseudopodzolic soils derived from loamy sands lying on heavier substrate | 1 858 | 12.2 |
| 8. Brown and pseudopodzolic soils derived from light loam | 1 897 | 12.5 |
| 9. Brown and pseudopodzolic soils derived from medium loam | 937 | 6.2 |
| 10. Brown and pseudopodzolic soils derived from heavy loam | 121 | 0.8 |
| 11. Brown and pseudopodzolic soils derived from shallow loam on light substrate | 570 | 3.8 |
| 12. Brown and pseudopodzolic soils derived from gravel | 88 | 0.6 |
| 13. Brown and pseudopodzolic soils derived from silts of water origin | 739 | 4.9 |
| 14. Brown and pseudopodzolic soils derived from loess and loesslike materials | 1 056 | 6.9 |
| 15. Brown and pseudopodzolic soils derived from clays | 50 | 0.3 |
| 16. Brown and pseudopodzolic soils derived from lithic rocks - loamy and skeleton-loamy | 168 | 1.1 |
| 17. Brown and pseudopodzolic soils derived from lithic rocks - loamy | 192 | 1.3 |
| 18. Brown and pseudopodzolic soils derived from lithic rocks - clayey | 38 | 0.3 |
| 19. Brown and pseudopodzolic soils derived from lithic rocks silty | 201 | 1.3 |
| 20. Heavy alluvial soils | 505 | 3.3 |
| 21. Light and very light alluvial soils | 211 | 1.4 |
| 22. Light and medium alluvial soils | 70 | 0.4 |
| 23. Black earths | 660 | 4.3 |
| 24. Black earths derived from sands | 394 | 2.6 |
| 25. Moorsh soils | 114 | 0.7 |
| Total | 15 206 | 100 |

The analysis undertaken showed that the only available source of information for geographically placing the soil profiles being studied was Witek's elaboration [18]. This included a surface structure of the aggregate soil groups according to the complexes of agricultural usability in the areas of individual districts. Hence, the structure of the spatial distribution of the profiles studied was created from the indications as to which soil unit samples should be taken from individual districts and which profiles should represent them. The geographical placing of the soil profiles, studied against a background of the relevant soil cover was done on the basis of a soil – agricultural map or a soil map on a scale of 1:500 000 or 1:300 000. Due to the morphological diversity of the soil profile structures and the different sequences of soil levels, the cartographic presentation of their properties was based on the division of the soil profile into three levels for the sake of uniformity:

– one level defined as a surface level referring to the arable level,
– one level defined as a subsurface level (sub-arable) that can be distinguished by the predominance of the mineralization processes of the organic matter which enters it,
– one level defined as subsoil, with the predominantly 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 in three replications. The documentation and soil material thus obtained was then used to set up a bank of soil samples [10, 17].

**Measuring methods**

The measurements of water retention curves of the Polish arable mineral soils, i.e., the relation between soil water potential and water content (moisture), were taken within the range from 0.1 kJ $m^{-3}$ (pF 0) to 1 500 kJ $m^{-3}$ (pF 4.2), at eleven points in the drying process (for the following pF values: 0, 1, 1.5, 2, 2.2, 2.5, 2.7, 3, 3.2, 3.7 and 4.2). Standard pressure chambers, (made by The Soil Moisture Company, Santa Barbara, California USA) were used. The amount of large pores was calculated as the difference between the water content at 0.1 kJ $m^{-3}$ (pF 0) and 16 kJ $m^{-3}$

(pF 2.2), the amount of medium pores – as the difference between water content at 16 kJ m$^{-3}$ (pF 2.2) and 1500 kJ m$^{-3}$ (pF 4.2) and the quantity of small pores – as the value of moisture at 1500 kJ m$^{-3}$ (pF 4.2). It was assumed that the amount of water available for plants called 'potentially useful retention' (PUR), is under Polish conditions, represented by 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). The border between the ease of availability of water for plants and difficulty is 100 kJ m$^{-3}$ (pF 3) [16, 20].

The results of the investigations, presented in this paper, are the average values, which come from 290 soil profiles, three genetic levels of these profiles and three replications (Figs 1–5).

## RESULTS

When analysing this summary of the results of the pore size distribution and the amount of water available for plants in the soil profiles, the specificity of variability and vertical non-homogeneity of the granulometric composition of Polish soils should be taken into consideration. The majority of Polish soils are derived from post-glacial materials. The peri-glacial, erosion and soil processes are the reason that soils derived from sands show a lighter granulometric composition in their deeper layers than do those derived from loam and clay. Alluvial soils are found in layers as a direct result of the way in which material travels – and is slowly deposited – along a river-bed. Soils with a homogeneous granulometric composition are derived from loess, loess-like materials and silt of water origin.

### Pore size distribution

The average amount of large pores (Φ>18.5 m) in the surface layer of arable Polish soils reaches maximum values (28.6%, v/v) in brown, rusty and podzolic soils derived from weakly loamy soils and loose sands. Slightly lower values (28, 24, and 23.3%) are noticed in brown and psuedo-podzolic soils derived from gravel, black earth derived from sands and moorshu soils. The minimal values of the large pores are in the brown and pseudopodzolic soils derived from clays (6.1%) and brown and pseudopodzolic soils derived from heavy loam (9.5%). At increasing depths the maximum and minimum number of large pores was 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 (Fig. 1).

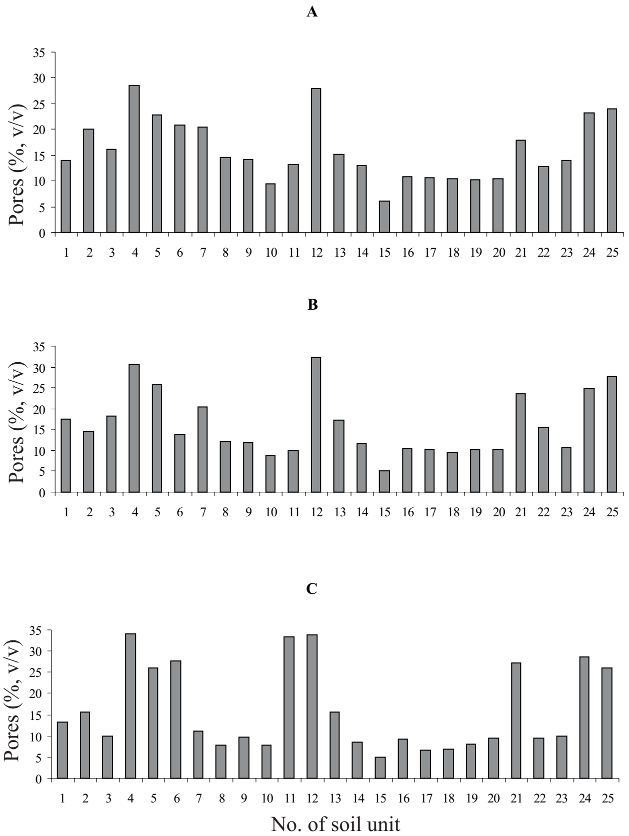


**Fig. 1.** Amount of large pores (Φ>18.5 m) in surface (A), subsurface (B) and subsoil (C) layers of Polish arable soils.

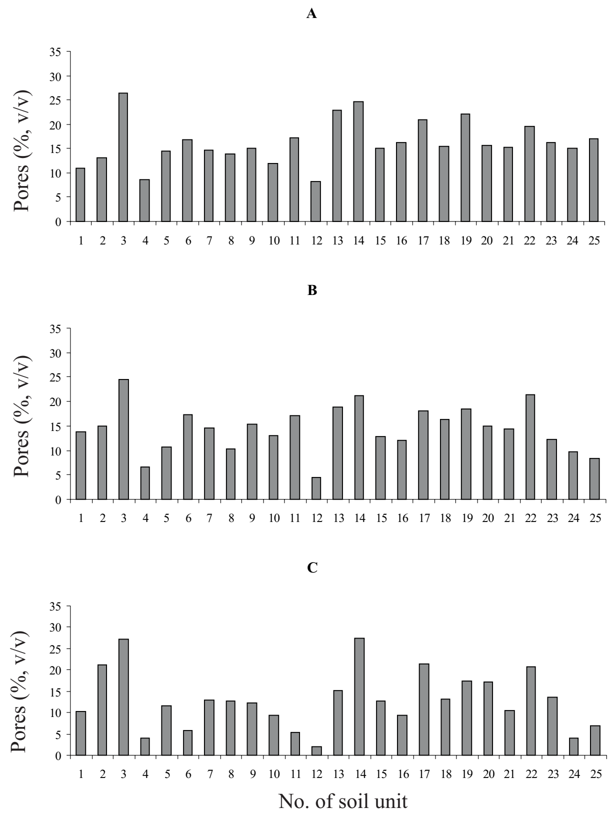


**Fig. 2.** Amount of medium pores (18.5<Φ<0.2 m) in surface (A), subsurface (B) and subsoil (C) layers of Polish arable soils.

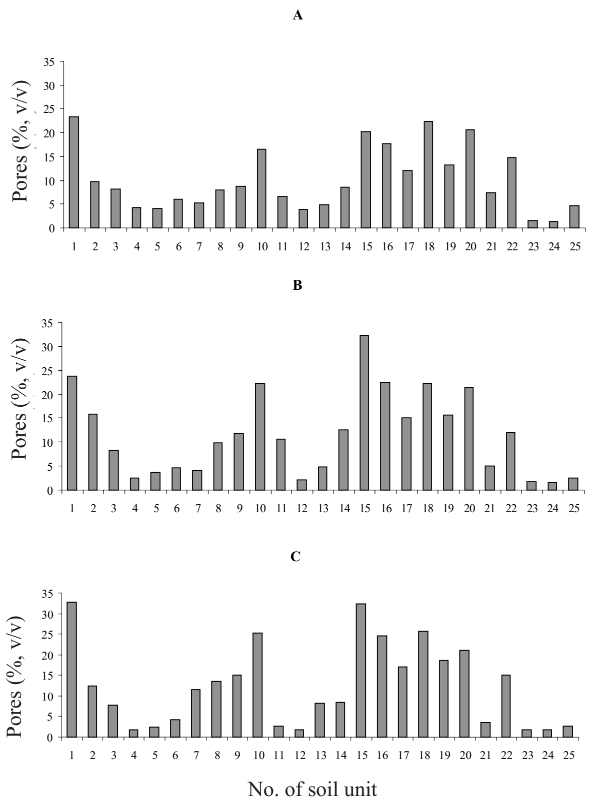


**Fig. 3.** Amount of small pores ($\Phi<0.2$ m) in surface (A), subsurface (B) and subsoil (C) layers of Polish arable soils.

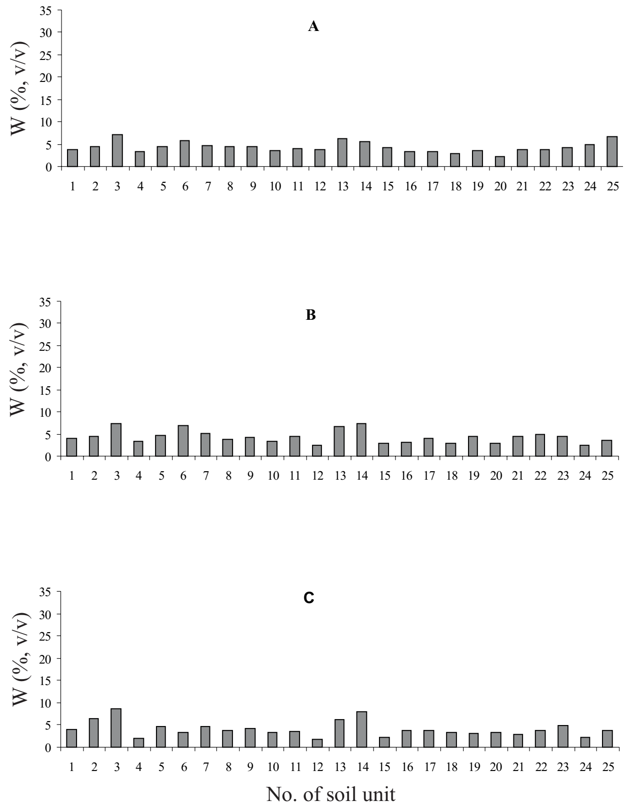


**Fig. 4.** Amount of water easily available for plants in surface (A), subsurface (B) and subsoil (C) layers of Polish arable soils.

The amount of medium pores ($18.5<\Phi<0.2$ m) 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% (Fig. 2). It reached the highest values in chernozems as well as in the brown and pseudo-podzolic soils derived from silt of water origin, loess and loess-like materials, whereas the lowest values were observed for brown, rusty and podzolic soils derived from light loamy sands, loose sands as well as brown and pseudo-podzolic soils derived from gravel. As with the large pores, the amount of medium pores generally decreases with the depth of the soil profiles.

The amount of small pores ($\Phi<0.2$ m) was largest for soils derived from clay, lithic rocks, rendzinas (pure) as well as brown and pseudo-podzolic soils derived from heavy loam (23.4–32.7%), whereas it was smallest (1.4–1.7%) for black earth and soil derived from gravel and sand (Fig. 3).

## Water availability for plants

The amount of water easily available for plants in Polish arable soils is presented in Fig. 4. 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% in the surface layer, from 2.4 to 7.6% in the subsurface layer and from 1.8 to 8.7% in the subsoil. Generally, the maximum amount of water was observed for chernozems and soil derived from silt.

The amount of water available for plants – but only with difficulty (Fig. 5) is much larger than water which is easily available and in the surface layer varies from 4.4 to 19.8%, in the subsurface layer – from 2 to 17.1% and in the subsoil – from 0.3 to 19.5%. The maximum quantity of this category of water is retained in chernozems, soil derived from silt, lithic rock and alluvial soil. Generally, the amount of water available for plants – but only with difficulty – decreases with the increase of the depth of the soil profiles.

In analysing the results of the investigations it can be stated that both varying porosity and the amount of water available for plants are connected with the parent materials and as a consequence with the granulometric composition of soils. It is very important that Polish soils retain a very small quantity of water available for plants – less than 9%, v/v. This phenomenon creates very uncomfortable conditions for plant production in Poland.

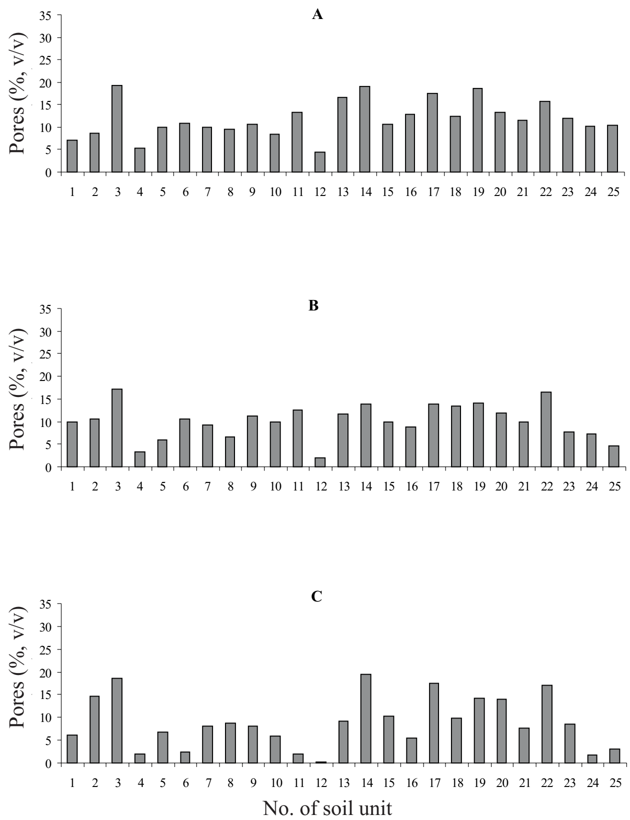


**Fig. 5.** Amount of the water available with difficulty for plants in surface (A), subsurface (B) and subsoil (C) layers of Polish arable soils.

## CONCLUSIONS

The results of the investigations presented here are the basis for the following conclusions:

1. Porosity and pore size distribution are connected with the varied nature of the granulometric composition of Polish soils.

2. The granulometric composition in particular layers of soil profiles determines pore distribution, i.e., the maximum amount of macropores is in the surface layer and the maximum amount of micropores is in the subsoil.

3. The amount of water available for plants is relatively large, but the amount of water easily available for plants is very small and does not exceed 9%, v/v.

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