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MORPHOLOGICAL DESCRIPTION OF PLANT ROOT STATUS IN THE DIFFERENT-STRUCTURED SOILS*

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A b s t r a c t. Morphological analysis of biopores formed by the plant roots was carried out on the opaque soil blocks in reflected light. The samples were taken from the genetic horizons of forest soils used for agriculture. We found that the plant roots were not centrically situated in the cross section of biopores but were usually more adjacent to one of the walls. In our investigation we did not observe the occurrence of any zones of compacted soil in the direct vicinity of the roots.

K e y w o r d s: soil structure, plant roots, biopores, morphological analysis

INTRODUCTION

The life conditions of plant roots strictly depend on the condition of the soil structure and, at the same time, plant roots significantly shape the soil structure. Root systems can use the existing pores of a given magnitude, or they must create some new pores (root canals) by surmounting soil resistance and pushing the root tip into the soil mass [4]. The roots change the soil structure when they shape the new pores and, also, when they widen already existing pores by penetrating them. In consequence, they reduce porosity in the zone which is adjacent to the root canal [7]. According to Dexter [3] the penetration of a root into a pore depends on the pore orientation in relation to the root, and on the resistance of the soil mass surrounding the root. Roots can exert their pressure both in the axial direction and transversally to the axis; both pressures are comparable, they amount to the value of 0.2-1.5 MPa [8]. Soil resistance is provoked by the packing of the soil particles and the „cementation" of the greater particles by the clay ones and by various kinds of inorganic and organic substances [4].

The behaviour of pores is significantly influenced by the occurrence of compact layers existing in the soil profile. The plough sole can reduce root penetration, or make it impossible. In such a situation roots grow horizontally along the upper border of the compacted layer until they find a vertical pore of a suitable diameter [6]. In order to prevent such unfavourable phenomena Elkins and Hendrick [5] proposed the so-called slit-plant tillage system, which consists in making vertical slits in the plough sole and creating a road for the deep penetration of roots.

When the soil is plastic, the roots are able to enlarge the already existing pores. The root capillary system is unable to create its own pores and therefore it is larger than itself (about 10 μm) [4].

In the majority of soils, independent of climatic zone, the largest concentration of plant roots can be found in the surface soil layer where nutritive substances are highly

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concentrated. At least one root of a given plant penetrates into the depth of the soil profile so that the plant can receive water and nitrogen compounds washed out from the upper layers of the soil [4]. According to Barley [1], in the case of crops the value 10 cm cm^{-3} is considered a large concentration of roots in the surface soil layer. It corresponds to an average distance between the root axes of about 3 mm. The roots, however, very seldom occupy more that 2 % of the whole soil volume. At the depth of about 1 m the root concentration is only about 1 cm cm^{-3} or even less. In the case of most plant species the roots reach only the depth of 1-2 m.

The biopores already existing in soil considerably facilitate the penetration of roots deeper into the profile, even when small vertical pores are only about 0.1 % (v/v) [6]. In the longer term the possibility of root penetration is determined by the durability of biopores. The determinant of durability is the resistance of biopores to the compaction, caused by the pressure of agricultural machine wheels [2].

The considerable high stability of wide pores is related to the origin of a small compact layer in the soil around the pores. Kay [7] reported that the diminishing porosity of soil around the roots, along with the influence of the organic material gathered in rhisosphere, results in a considerably higher resistance and stability of the root zone (after the roots die out). The channels left become a very important zone for the flow of water, gas exchange and the growth of new roots.

The scope of the present paper is the morphological analysis of the genetical layer of the soils cultivated in various ways. Special attention was paid to the zones around plant roots.

OBJECTS AND METHODS

The investigation was carried out on a special kind of preparation used for the morphological analysis of soil in the reflected light of opaque soil blocks. The soil samples used to the preparation of the soil blocks were taken from the following genetical horizons of various soil profiles:

1) Horizons O and Ah of Haplic Luvisol formed from loess, a depth of 0-8 cm, hornbeam, oak and pine trees in the forest, Czesławice, Plateau of Nałęczów;

2) Horizons O and Ah of Haplic Luvisol formed from loess, a depth of 0-8 cm, pine, oak and hornbeam trees in the forest, Huta Turobińska, Western Roztocze;

3) Horizons O and Ah of Haplic Luvisol formed from loess, a depth of 0-8 cm, hornbeam and beech trees in the forest, Zrąb, Działy Grabowieckie;

4) Horizon Eet of Haplic Luvisol formed from loess, a depth of 10-18 cm, hornbeam and beech trees in the forest, Zrąb, Działy Grabowieckie;

5) Horizons O and Ah of Haplic Phaeozem formed from loess, a depth of 0-8 cm, hornbeam and oak trees in the forest, Werbkowice, Hrubieszów Basin;

6) Horizon Ap of Haplic Luvisol formed from loess, a depth of 0-8 cm, cultivated field intensively used with full mechanisation, winter wheat Czesławice, Plateau of Nałęczów;

7) Horizon Ap of Haplic Luvisol formed from loess, a depth of 0-8 cm, cultivated field belonging to a private farmer, the cultivated plant: potatoes, Wojsławice, Działy Grabowieckie;

8) Horizon Ap of Haplic Phaeozem formed from loess, a depth of 0-8 cm, cultivated field belonging to a private farmer, the cultivated plant: winter wheat, Oszczów, Gręda Sokalska.

Soil samples, of preserved natural vertical collected in measuring structure were in metal containers 9x8x4 cm. After the soil was dried at room temperature. The samples were impregnated with polyester resin POLIMAL-109. The resin was diluted with monostyrene in the proportion of 600 ml of monostyrene to 1000 ml of resin. 2% cobalt naphtenate was used as the substance to initiate polymerisation. A paste of cyclohexanone hydroperoxide, dibutyl phthalate was used as a catalyst. The mixture used, corresponded, to 1.5 ml and 5 ml for 1000 ml of resin. The impregnation was carried out in a vacuum drier at an absolute pressure of 20-30 hPa. After the samples were saturated with the resin, the containers with the samples were placed in a ventilated chamber where the temperature was kept constant, equal to 20°C (± 1°C). The process of polymerisation of the resin took place after about 8-10 weeks.

The hardened soil blocks were cut vertically into slices 1 cm thick with the help of a cutter with a diamond target of 2 mm of thickness (cooled with naphtha). The slices were ground and polished with the help of corundum powders and glass-paper of varied grain-size distribution (80-1000). The received soil blocks were used for morphological analysis aided by a computer image analyser, IMAGER-512. At the next stage of investigation the received images were processed in WINDOWS 3.1 and printed by an ink jet, differentiating 256 levels of greyness. Consequently the stable phase of the soil shows a full range of greyness, the root sections are characterised by the domination of white, and the spaces filled with the resin black. For the sake of a better presentation of the most characteristic zones around the roots, the sections of the real image were enlarged twice.

RESULTS

The computer generated images made it possible to observe plant root sections both in the loose and compacted soil.

They also made it possible to see the shape and dimensions of the soil pores and the situation of roots in their interior.

Within the whole 0-8 cm layer (horizons O and Ah) of the forest Haplic Luvisol from Czesławice (Fig. 1A) there are numerous roots, most of them within the horizon O reaching to the depth of about 3 cm. The visible tree roots of the greatest cross section in the eyeshot up to 8 mm are always surrounded by wide biopores. Most often the root is not situated strictly in the centre of a pore, but more adjacent to one of its walls (Fig. 1B).

Within the surface layer (horizons O and Ah) of the forest Haplic Luvisol from Huta Turobińska there are numerous cross and oblong sections of the roots (Fig. 2A). Just as it was in the previously described soil, this one is surrounded by biopores of a regular, circular shape. Especially interesting is the cavity left by a died root, which can be clearly seen on the enlarged fragment of the preparation (Fig. 2B). The hard tissue covering the root did not decompose.

In the preparation from the layer 0-8 cm (horizons O and Ah) of the forest Haplic Luvisol from Zrąb can be observed the effect of several roots running at a small distance one from another (Fig. 3A). These roots made some wide cavities in their direct neighbourhood, creating, a network of cracks, influenced the capability of the soil to transport

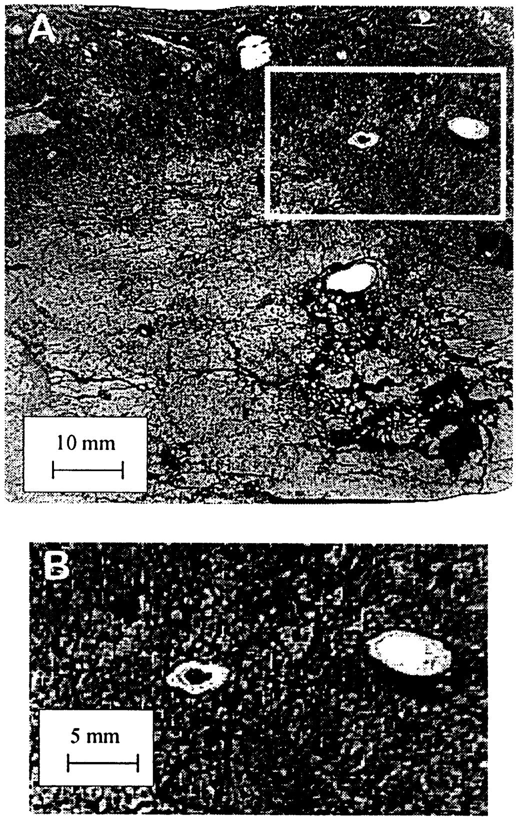


Fig. 1. The Haplic Luvisol, Czesławice, the forest. A) The image of the complete soil sample of natural dimensions, taken from the layer 0-8 cm; B) Section of the image, made twice larger. The root sections are characterised by the domination of the white colour, soil solid phase - grey colour and the spaces filled with the resin are black.

water and exchange gases. In a similar way as on Fig. 1 the roots of a large cross section have a tendency to adjoin to one of the walls of the pore (Fig. 3B).

Layer 10-18 cm (horizon Eet) of the Haplic Luvisol from Zrąb is much more compact than the layer 0-8 (horizons O and Ah). It is characterised by a non-aggregated structure, with a domination of pores of the second range: narrow, horizontal cracks (Fig. 4A). There are definitely less plant roots at this depth. Those of them, however, that occur, modify the soil structure by loosening the compact soil mass (Fig. 4B).

In the Werbkowice forest the green cover and the thick undergrowth formed from hazel and bird's cherry was very strongly developed. On the preparation of the layer 0-8 cm (horizons O and Ah) of the humus, there are no large lignified roots, as shown in the previously described soil blocks. Within the humus soil there is a large population of mesofauna of, especially, rainworms. The effect of their activity produces a biogenic structure with predominance of crumb aggregates which is standard. The plant roots use the cavities formed by the animal organisms and penetrate them. This can be observed on the upper part of Fig. 5A as well as on the enlarged fragment in Fig. 5B.

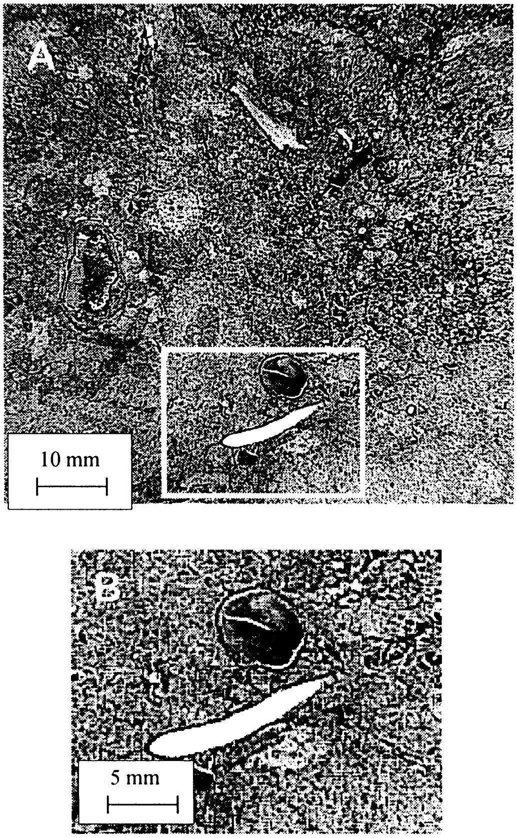
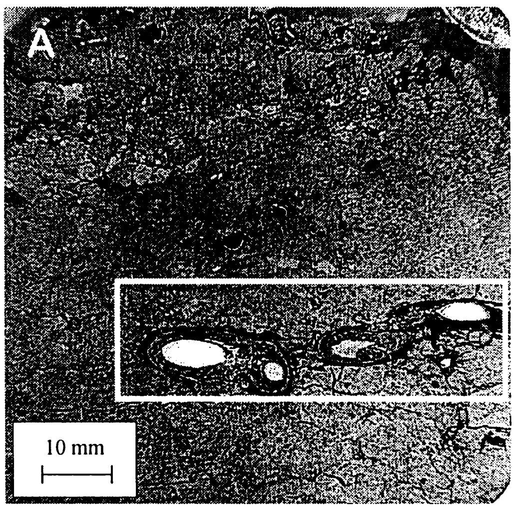


Fig. 2. The Haplic Luvisol, Huta Turobińska, the forest. The remaining explanations as under Fig.1.



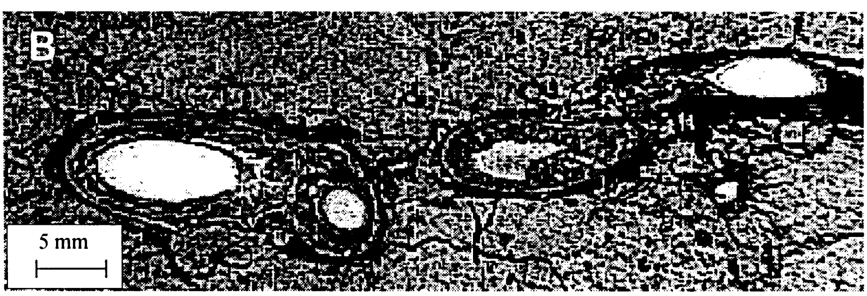


Fig. 3. The Haplic Luvisol, Zrąb, the forest. The remaining explanations as under Fig.1.

Layer 0-8 cm (horizon Ap) of the Haplic Luvisol, intensively used agriculturally, is considerably compact because of mechanical tillage over many years (Fig. 6A). In consequence the type of structure is characteristic of intensively pressed soils of silt granulometric composition, with a distinct domination of the horizontal cracks. The plant roots usually occur in layer 4 cm, penetrating the already existing network of cracks (Fig. 6B).

In the preparation from layer 0-8 cm (horizon Ap) of the Haplic Luvisol used for agriculture there are distinctly visible two zones, an upper one, made soft during the spring field work, and a lower compacted one, with a domination of narrow long cracks (Fig. 7A). In the compacted zone the presence of the pore-cavities is strictly connected with the occurrence of roots (the first fragment of the picture, Fig. 7B).

Without any doubt the existence of such cavities does facilitate the stream of water and air within the compacted soil mass especially when the root does not fill the whole pore. On the second fragment of the picture there is a root going through the broad cavities, caused by the effect of soil fauna activity (Fig. 7C).

Within layer 0-8 cm (horizon Ap) of the Haplic Phaeozem can be seen the numerous soft zones made by intense soil fauna activity (Fig. 8A). The results of such an activity is the formation of numerous biogenic aggregates, situated rather loosely within the free soil space, and broad cavities. These are such cavities that the roots of the cultivated winter wheat are passing through. As it can be clearly seen, and as it was previously stressed, they do not occupy the central part of the pores, being adjacent to one of the pore walls (Fig. 8B).

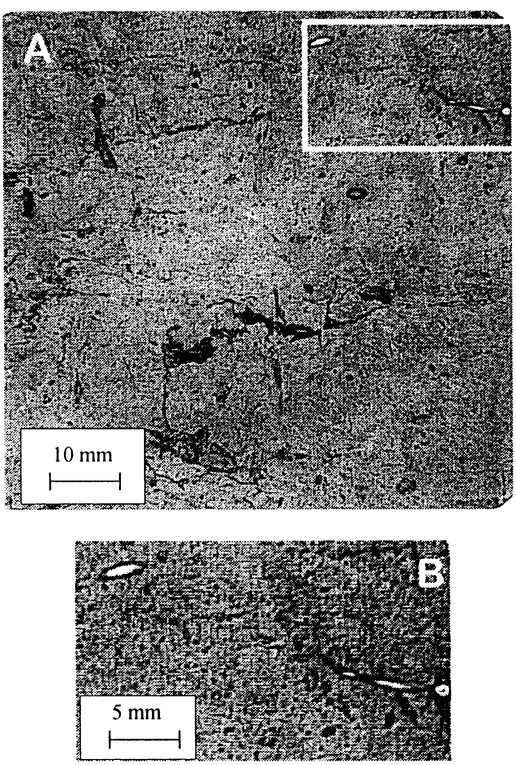


Fig. 4. The Haplic Luvisol, Zrąb, the forest. A) The image of the complete soil sample of natural dimensions, taken from the layer 10-18 cm; B) Section of the image, made twice larger.

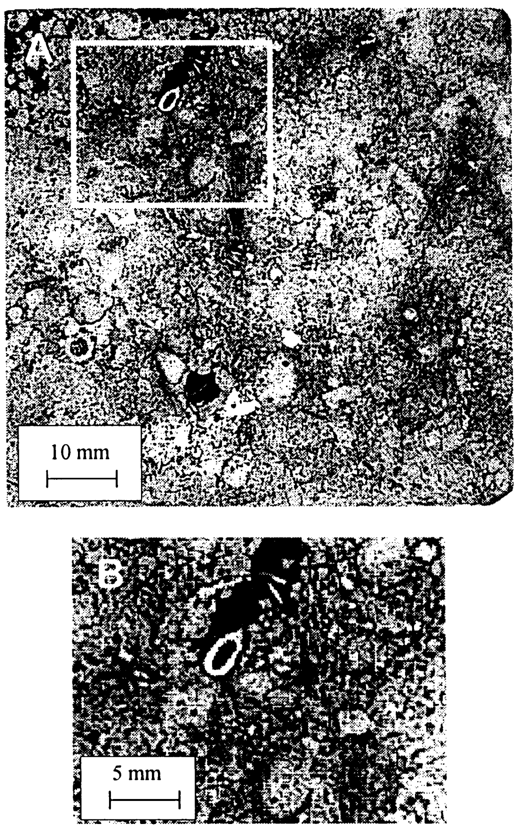


Fig. 5. The Haplic Phaeozem, Werbkowice, the forest. The remaining explanations as under Fig.1.

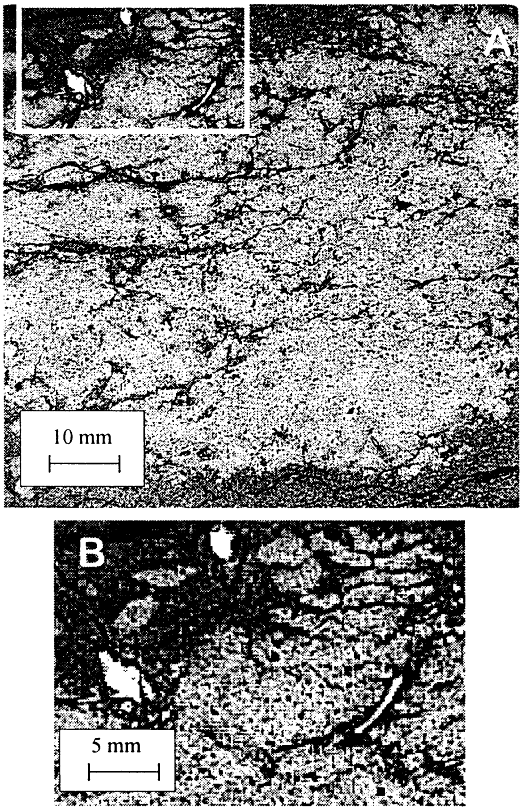


Fig. 6. The Haplic Luvisol, Czesławice, the cultivated soil. The remaining explanations as under Fig.1.

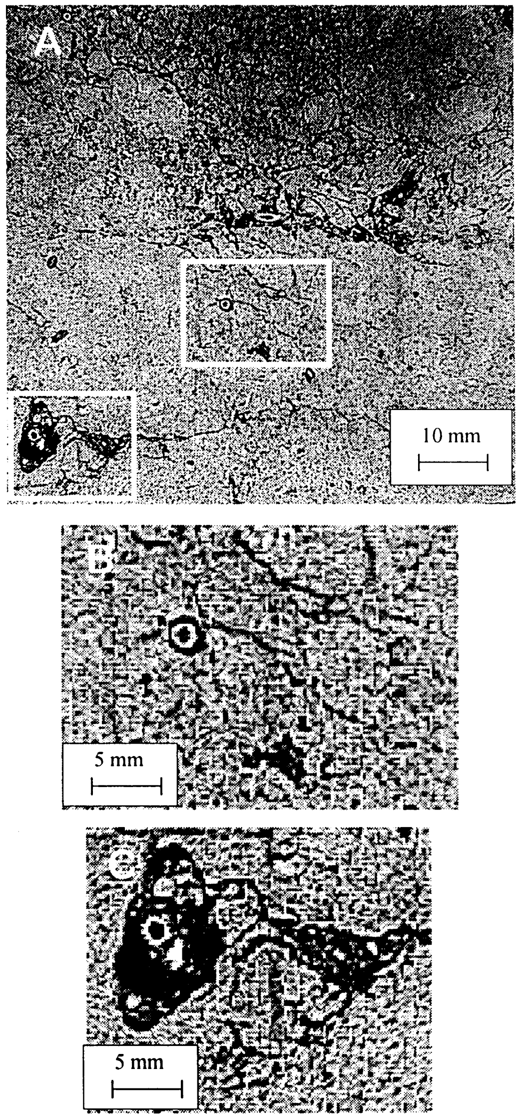


Fig. 7. The Haplic Luvisol, Wojsławice, the cultivated soil. A) The image of the complete soil sample of natural dimensions, taken from the layer 0-8 cm; B), C) Sections of the image, made twice larger.

The tree roots which appear in the surface horizons of the forest soils are always surrounded by wide biopores. Most often the root is not situated in the centre of the biopore, being rather adjacent to one of its walls. This facilitates the reception of water and nutrition components. According to Van Noordijk *et al.* [9] the most effective reception of water takes place in such cases when the contact between the root and the soil is equal to 100 %. When all the roots are not in complete contact with the soil the aeration worsens.

Within the compacted layers of the cultivated soils pressed by the wheels of agricultural machines the dominating type of pores are narrow, horizontal cracks. This type of structure facilitates gas exchange and water filtration. The plant roots are grouped in such cases within the surface soil layer, while the surrounding zones are loosened. Numerous cracks are situated radially from the biopores surrounding the thicker roots. In the morphological studies we carried out the occurrence of heavily compacted zones of a heavy soil within the direct vicinity of roots was not confirmed. The existence of such zones should be expected around granary roots, in case of sugar beet or fodder or carrot. The morphological analysis of the structure of the soil

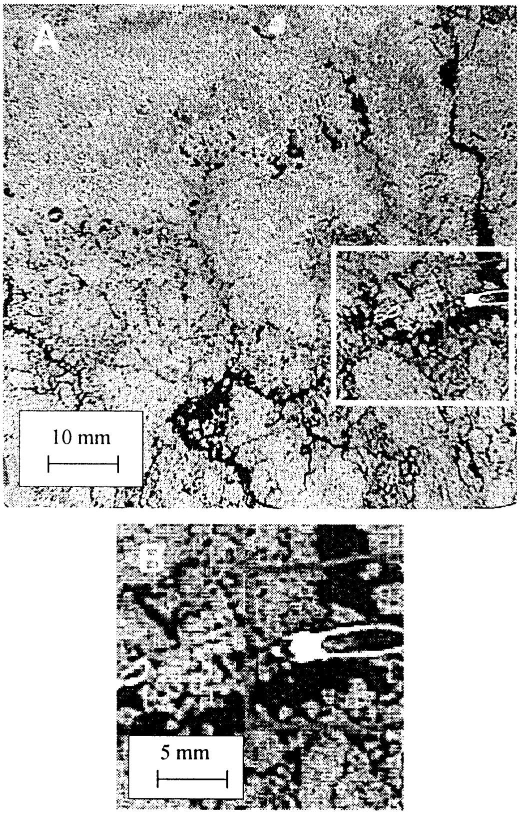


Fig. 8. The Haplic Phaeozem, Oszczów, the cultivated soil. The remaining explanations as under Fig.1.

adjacent to the granary roots is going to be the theme of further investigation.

CONCLUSIONS

1. It was found that the plant roots are not situated centrically within the cross section of biopores, being usually adjacent to one of the walls.

2. The existence of zones of increased compaction of soil was not observed in the direct vicinity of roots.

3. In the soils which had been considerably pressed, the plant roots are grouped first of all within the surface layer of the cultivated soil, profiting from the already existing cracks.

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