ANALYZING SOIL POROSITY UNDER DIFFERENT TILLAGE SYSTEMS USING X-RAY MICROTOMOGRAPHY

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Abstract

X-ray computed tomography is one of the modern techniques used for soil structure visualization and quantification. The aim of this study was to investigate the effects of different tillage systems on soil porosity. Soil samples were collected from the field, on 0-30 cm depth, within the Experimental Farm of the Agricultural University of Iasi, North East of Romania, from a long term experiment with three tillage systems: V1 - chisel, V2 – no-till, V3 - plough at 30 cm. Aggregates were scanned using a SkyScan 1172 microCT and then the reconstructed 3D images were analyzed, in order to investigate pore volume and pore size class distribution. The results of the porosity analysis revealed significant differences between the variants taken into study. Regarding the solid surface area the tillage systems determined very different values of this parameter in soil. Pore size class distribution also showed clear differences between the variants. X-ray CT proved to be a useful tool for soil analysis, in order to have a detailed view of the pore network.

Key words: (soil porosity, X-ray CT, tillage system)

The tillage system affects soil porosity and thus its ability to provide optimal conditions for plant development, organic matter mineralization and water and nutrient transport (Garbout *et al*, 2013).

Recent advances in non-destructive imaging techniques, such as X-ray computed tomography (CT), make it possible to analyze pore space features and to understand how soil physical properties are influenced by different tillage works. In its yearly years, this technique was used to describe macro-structures such as biopores (Gregory *et al*,. 2003, Capowiez *et al*, 2003), dense layers (Lipiec and Hatano, 2003) and plant roots (Pierret *et al*, 1999), but its quick development allowed the quantification of soil pore space on very detailed images, with voxels <50µm (Munkholm *et al*, 2012*;* Schulter *et al, 2011;* Peth *et al*,2010*;* Quinton *et al*,2009).

Solid-pore space is organized by its different scales: large bio-pores, inter-aggregate pores and small pores inside aggregates (Bronick and Lal, 2005). In the last years, several studies have shown that soil heterogeneity and complexity at small scales determine its functionality and sustainability at larger scales (De Bartolo *et al*, 2011*;* Crawford, 2010*;* Jacobson *et al*, 2007).

The aim of this study was to quantify soil porosity using a microCT scanner, in order to see the influence of different tillage systems on soil physical state.

MATERIAL AND METHOD

The experiments started 10 years ago and were carried out within the Experimental Farm of the Agricultural University of Iasi, in the NE of Romania, on a cambic chernozem, with medium level of fertilization, with clay-loamy texture, 6,7 pH and 3.5% humus content. The long term amount of precipitation is 517.8 mm and the annual average air temperature 9.4 ^{o}C. The experimental variants included: V1 - chisel, V2 – no-till, V3 - plough at 30 cm. They were arranged in a split plot design, with three replications and all treatments remained in the same place each year. Each plot had 60 m^2, separated 1 m buffer zone. It was used a three years rotation with maize, soybean and winter wheat.

The CT scans and image analysis were carried out within the Research Institute for Agriculture and Environment of Iasi.

Eight soil cores (Ø=3 cm, height = 4 cm) from each variant were collected from the field, during the vegetation stage of the crop, from two different layers (5-15 and 20-30 cm depth) and then scanned using a SkyScan 1172 microCT (Bruker, Kontich, Belgium), at 80 kV, 100 mA and a voxel size of 6.79 µm. In order to achieve better image quality, the samples were scanned over 360 degrees with a rotation step of 0.4 degree and the random movement parameter was set with

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amplitude (in number of detector lines) of 10, which can reduce ring artifacts in the reconstruction cross sections. To reduce beam hardening effects which appear because of a preferential absorption by the borders of the sample, a combination of two metallic filters were used: aluminum and copper.

For the reconstruction of the cross-section images, the NRecon® (v.1.6.10.1) program package was used, and the image processing analysis was performed using CTAn® (v.1.15.4.0) software. The software allows segmentation of different phases related to the attenuation coefficient and/or material density, image processing procedures and quantification of several morphometric 2D/3D parameters, such as porosity. In order to separate porosity from sediment matrix, multi-level thresholding mode (imbued in CTAn®), for two different phases beyond the pore phase, was used, which is based on the automatic Otsu's method (Nobuyuki, 1979), it is an automatic type of thresholding without manual interference (Munkholm *et al,* 2012). Within this method, the white voxels are included in the volume of interest (VOI) that was set exactly equal to the boundary of the sample (ROI Shrink-Wrap). The false objects were erased using a despeckle plugin, to limit the random noise. At the end, the binary images contain white pixels representing the pore space and black pixels corresponding to sediment structures.

RESULTS AND DISCUSSION

In table 1 are shown the results regarding the porosity, for all 3 variants taken into study. The detectable pore space (>6.8 µm) was divided into two categories: open porosity (pores connected to air) and closed porosity (isolated or unconnected pores).

Table 1

Porosity categories (%) for all tillage variants

Sample	Depth (cm)	Closed porosity (%)	Open porosity (%)	Total porosity (%)
Chisel	5 – 15	1.89	19.67	21.56
	20 – 30	3.11	20.25	22.72
No-till	5 – 15	1.66	23.27	24.54
	20 – 30	0.17	33.94	34.05
Plough at 30 cm	5 – 15	0.33	29.11	29.35
	20 – 30	0.03	43.62	43.64

The total porosity had the highest values for the ploughed variant, on both soil depths, but only on the 20-30 cm layer, it had values closed to the ones recommended by literature (Jităreanu, 2015). In an ideal soil, the pores occupy 50% of the total volume. As we can see, the deeper soil layer remained loosen, while the upper one got more compacted due to the works applied and also due to weather conditions along the year. The results obtained for this tillage system are not surprising, due to the fact that the soil was worked 30 cm depth every year.

The lowest values were recorded for the Chisel variant, on both soil layers. There were small differences between the values of each layer within the same variant.

The No-till variant had intermediate values, for both depths, with higher porosity in the deeper layer. Even if the difference compared to the ploughed variant is quite high, it's worth to notice that ten years of applying this tillage system lead to better results compared to the Chisel variant.

As it can be noticed, the highest values of the closed porosity (%) were registered for the Chisel variant, on both analyzed depths. The lowest values were recorded for the ploughed variant. Closed porosity doesn't have any role in water, air and nutrient transport, but it influences the soil bulk density. Intermediate values were registered for the No-till variant.

Regarding the open porosity, the highest values were recorded, as expected due to soil tillage, in the ploughed variant, on both analyzed depths (29.11 % for the 5-15 cm layer, 43.62 % for the 20-30 cm layer). The No-till variant had intermediate values, on both soil layers. The chisel variant had the lowest values of this parameter, on very soil layer (19.67 % on the 5-15 cm layer, 20.25 % on 20-30 cm depth).

Figure 1 presents the pore classes, for each variant and depth. The pores were divided in 6 categories, depending on their diameter (<50 µm, 50-250 µm, 250-500 µm, 500-750 µm, 750-1000 µm and >1000 µm).

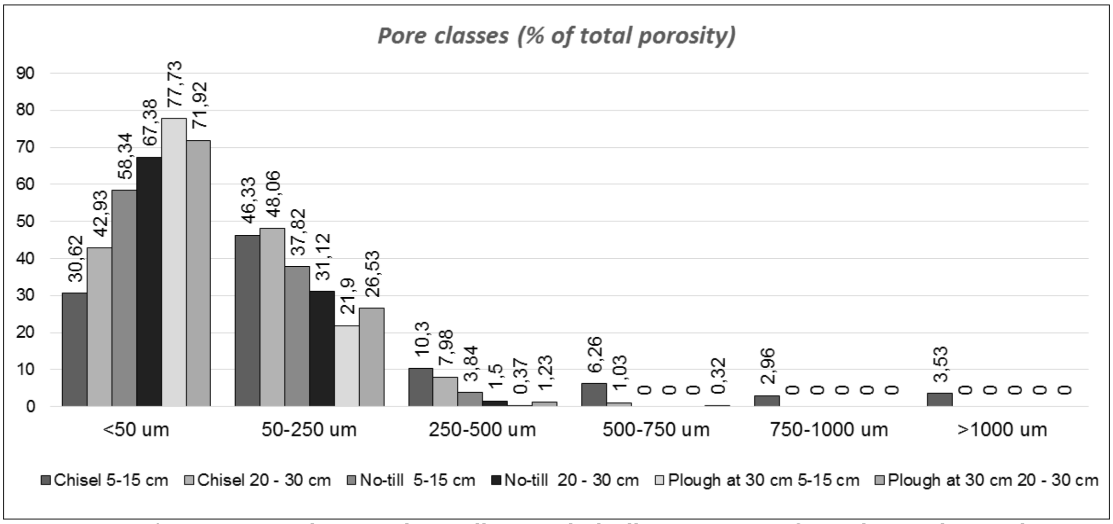

Figure 1 **Pore classes, depending on their diameter, as % from the total porosity**

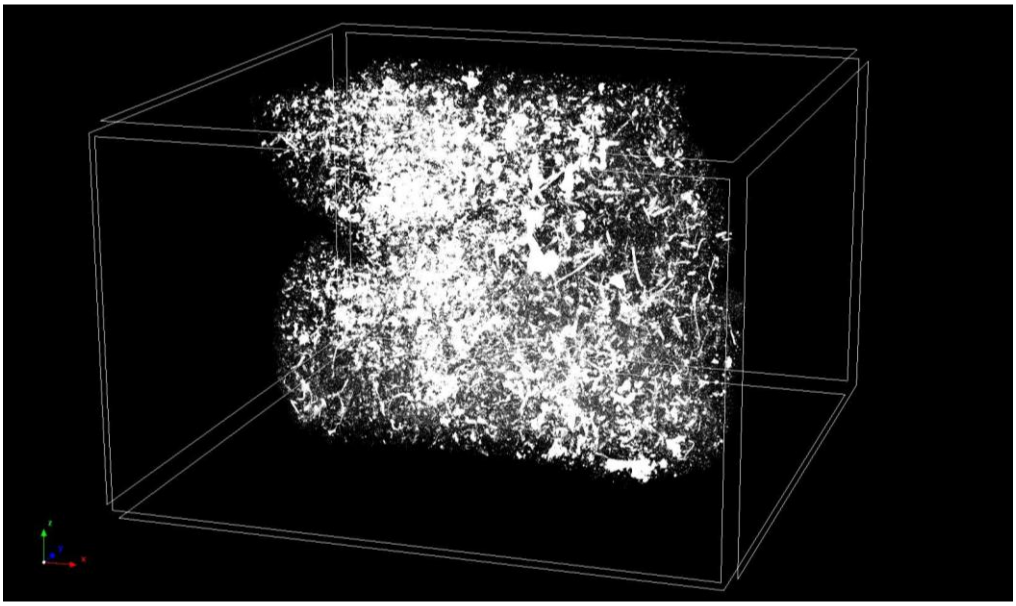

Figure 2 **Visualization of pore structure from the X-ray imagery of six different samples**

The Chisel variant, from the 5-15 cm layer, had 30.62% pores <50 µm, 46.33 % pores with a diameter of 50-250 µm, 10.3% pores with a diameter of 250-500 µm and small amounts of pores belonging to the other categories. This variant is the only one having pores of all categories.

The samples from the 20-30 cm layer of the same tillage had 42.93 % pores < 50 µm, 48.06 % pores with 50-250 µm diameter, 7.98% pores with 250-500 µm diameter and 1.03 % pores of the fourth category.

The No-till variant, from the 5-15 cm layer, had 58.34% pores < 50 µm, 37.82 % pores with 50-250 µm diameter and 3.84 % pores with 250-500 µm diameter.

The aggregates from the next soil layer of this tillage system had 67.38 % pores <50 µm, 31.12 % pores with 50-250 µm diameter and 1.5 % pores of 250-500 µm.

The samples from the ploughed variant, in the upper layer of 5-15 cm, had the highest percent of pores <50 µm (77.73%), followed by the ones from the next layer (20-30 cm), with a percent of 71.92 %. This variant, on both layers, recorded the lowest percent of pores with 50-250 µm diameter. The percent of pores from other categories is insignificantly low.

Figure 2 shows an example of 3D distribution of pore size in a sample taken into study in this paper.

CONCLUSIONS

The micro CT scanning and analysis revealed that the highest porosity was recorded, as expected, for the ploughed variant, on both corresponding layers. This variant had the highest percent of pores <500 µm. The No-till variant had better values compared to Chisel, fact that recommends this tillage system to be used, also due to other well-known benefits.

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