Image analysis of differently managed clayey surface soils of Finland

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Abstract

The porosities and pore shapes of boreal clayey surface soils (5 cm) were studied using image analysis of soil thin sections. The three adjacent sites investigated were vegetated buffer zones (BZs), which were either grazed, harvested or not managed at all. The purpose of the study was to evaluate the impact of these management practices on the surface soil structure of BZs. Water infiltration is essential for functioning of the BZs, as it reduces overland flow and contributes to reduced load from agricultural areas to water bodies. The results revealed that macro porosity (> 50 µm) was high in all studied sites. The majority of the macro pores consisted of large (>1000 µm) elongated irregular pores, indicating a complex and well-interconnected pore system, which is conducive to water infiltration. The differences between the studied sites were smaller than expected. It was hypothesized, that biological activity and fluctuating soil moisture typical of the boreal climate zone, i.e. wetting-drying and freezing-thawing cycles, might have reduced off the differences in the surface soil structure in the studied sites.

Key Words

Image analysis, soil structure, porosity, clay soil, buffer zone, boreal climate

Introduction

Vegetated buffer zones (BZ) are established to mitigate erosion and nutrient load from agricultural areas to water bodies. For the proper functioning of BZ, the structure of the surface soil should allow adequate infiltration in order to reduce overland water flow. Regardless of management practice, the surface soil structure of BZ should not be damaged. In Finland, vegetation from BZ is commonly removed by grazing cattle, but this practice may have destructive effects on soil structure (Pietola, 2005).

For decades, soil micromorphology has been qualitatively used to study soil structure as it appears in nature (Kubiena, 1938). In the 1970s, technological development allowed quantitative detection of soil porosity with computer aided digital image analysis of soil thin sections (e.g. Murphy *et al*., 1977). Image analysis proved to be an efficient tool to study differences in soil structure under various management practices or treatments (Ringrose-Voase, 1991). For example, changes in pore number, pore size distribution and pore shape pattern have been used as indices of the effects of conventional and zero tillage on soil structure (Pagliai *et al*., 1984).

The aim of this study was to document the surface soil porosity, especially the complexity of the pore system, of three differently managed vegetated BZs using soil thin sections. Quantitative information of pore size, number, and shape was obtained using image analysis. This study contributes to increasing of structural properties of boreal clay soils in general. More specifically, these results help assess the effects of different management practices on the functioning of vegetated BZs.

Material and methods

Experimental area and soil sampling

Soil samples were taken from a Vertic Stagnic Cambisol (IUSS Working Group WRB 2006) at Jokioinen, in southwestern Finland (60° 48' N, 23° 28' E). The texture was silty clay (clay 51%, silt 42%, and sand 7%). Three replicates of undisturbed soil samples were collected from the surface soil of three adjacent experimental areas, differing in management practice and vegetation, to prepare soil thin sections. These sites were a) 14-year-old natural vegetation with grass species and scrubs at natural state (natural), b) 14-year-old vegetation with grass species, harvested once a year (harvested) and c) 3-year-old vegetation with grass species, grazed by cattle (grazed). The names in parentheses are used later on.

Preparation of soil thin sections

Water was removed from the soil by wet dehydration applying a graded series of acetone (Tippkötter et al., 1986). Unsaturated polyester resin (Palatal P50-01, Büfa) with acetone as a thinner was used for the

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1 – 6 August 2010, Brisbane, Australia. Published on DVD.

embedding of these samples (Tippkötter and Ritz, 1996). Polymerization time was set by the concentrations of the hardener CHP (1.7 ‰) and the cobalt-accelerator (0.85 ‰) and resulted in seven weeks at room temperature. Totally, nine vertical thin sections were produced.

Image acquisition and analysis
Thin sections were placed on a transilluminator and images for the analyses of porosity were taken with a digital camera (Canon EOS 350D; 8 megapixels). These images were transformed to binary images (Photoshop CS, Adobe) and the image analysis software AnalySIS 3.2 (Soft Imaging) was used to measure pore area (A), perimeter (Pe) and convex perimeter (Peco) for pores larger than 50 µm equivalent pore diameter (EPD). The form factor (F) was calculated by the equation $F = A\ Pe^{-2}$. Elongated pores have a form factor <0.015, for irregular pores this factor is 0.015–0.04 and for rounded pores >0.04 (Bouma *et al.*, 1977). Elongated pores were further classified into four shape classes according to Pagliai *et al.* (1984): convex perimeter per perimeter ratio is <0.3 for very irregular pores, 0.3–0.5 for moderately irregular pores, 0.5–0.7 for moderately regular pores and >0.7 for regular pores.

Results

Soil porosity (equivalent pore diameter > 50 µm), expressed as a percentage of investigated area, was highest (17%) in the grazed site, whereas in the natural and harvested sites the porosity was 14% and 12%, respectively (SE 3.9, LSD 13.4). The number of pores per cm^2 varied between 97 and 118 (SE 7, LSD 23).

Soil porosities expressed as a percentage of investigated area in different shape classes according to shape factor are presented in Table 1. Elongated pores contributed major proportion of the porosity, with the minor variation between the sites. The number of pores per cm^{-2} decreased in the following order: elongated < irregular < rounded.

Table 1. Porosity in different pore shape classes in vertical thin sections expressed as a percentage of total porosity and the number of pores per cm^2. Results are averages of three thin sections. Standard errors (SE) and least significant difference (LSD) are with 6 degrees of freedom.

	% of total porosity			Number of pores per cm^2		
	Rounded	Irregular	Elongated	Rounded	Irregular	Elongated
Natural	1	4	95	46	33	18
Harvested	2	6	92	57	41	20
Grazed	1	4	95	48	38	21
SE	0.5	1.4	1.9	3.0	3.1	1.8
LSD	1.7	4.9	6.6	10.5	10.8	6.1

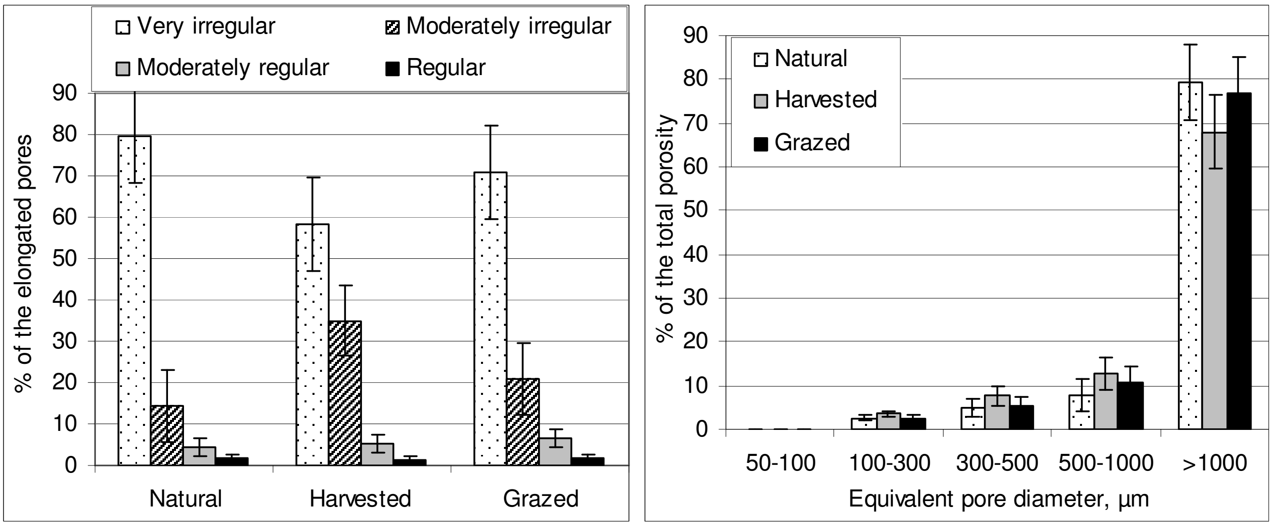

Figure 1. Pore shape distribution of elongated pores analyzed by image analysis in vertical thin sections (left). Pore size distribution (EPD) of elongated pores analyzed by image analysis in vertical thin sections (right). Error bars indicate standard errors of the means.

The shape distribution of elongated pores expressed as a percentage of porosity related to elongated pores

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(representing over 90% of the total porosity) is presented in Figure 1 (left). High irregularity was typical for elongated pores, less than 10% of them were classified regular and moderately regular pores, irrespectively to management practice. A clear majority of the porosity consisted of pores larger than 1000 µm EPD (Figure 1, right). Differences between the studied sites were minor.

Discussion

Soil macro porosity (equivalent pore size > 50 µm) was large in the surface soil of all studied sites. Detected pores were divided into three shape classes: rounded, irregular and elongated, according to form factor. Less than 10% of the porosity consisted of rounded and irregular pores. All rounded pores belonged to the size classes smaller than 300 µm EPD, probably generated by small roots and soil fauna (VandenBygaart *et al*., 1998). Pores belonging to the elongated class were studied in more detail because of their high relevancy.

Classification of pores according to ratio between the convex perimeter to perimeter divides pores into classes ranging from regular (rectangular pores) to the very irregular (tortuous, curved, digitate, U-shaped pores). The majority of the elongated pores were characterized by irregularity, which expresses the complexity and interconnectivity of the pore system (VandenBygaart, 1999). Moreover, the pore size distribution of the elongated pores revealed that far over 65% of the detected soil macro porosity was composed of large elongated pores >1000 µm EPD.

Differences in soil porosity between studied vegetated buffer zones were less evident than expected. In the boreal climate periods of water saturation, dry spells and freeze-thaw cycles have an impact on soil structure. These factors, together with biological activity, level off differences in soil structure (Sveistrup *et al*., 2005).

Conclusions

The macro porosity was large in all studied sites. It was strongly dominated by large elongated and irregular pores. This indicates a complex and well-interconnected pore system, which favors water infiltration into the soil. Seasonal changes in soil moisture content and biological activity were suggested to level off differences between the studied sites managed differently. Image analysis provided valuable information about soil porosity, but did not lead to an unambiguous conclusion whether vegetated BZ can be grazed without detrimental influence on surface soil structure. Further studies, such as qualitative description of thin sections and additional image analysis of horizontal thin sections are still needed to verify these results.

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