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Assessment of soil structure in the transition layer between topsoil and subsoil using the profil cultural method

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ABSTRACT

In France, agronomists have studied the effects of cropping systems on soil structure using a field method based on a morphological description of soil structure. In this method, called "profil cultural" or soil profile in English, the soil structure of the tilled layer is observed on a vertical face of a pit. Subsoil and more especially the transition layer between topsoil and subsoil have not always been given specific consideration. However, these layers undergo the effect of cropping systems through soil compaction or smoothing/smearing. A more accurate quantification of earthworm macropores and cracks in the transition layer would enable a more precise evaluation of the agronomical potential of the soil, manifest in root development or water retention. Thus, the aim of this paper is to present the profil cultural method in detail, along with the improvements we have made to quantify the ability of roots to penetrate compacted zones in the transition layer. We propose two indicators: (i) number of earthworm burrows per m^2 counted on a horizontal surface at the bottom of the transition layer in the soil pit (ii) cracking quantified by taking a 50-mm × 50-mm × 100-mm sample of soil from the transition layer and examining the number of cracks. Results from experiments on different tillage treatments are used to demonstrate why it is worthwhile to take into account cracks and earthworm activity. Soil profiles were examined in mouldboard ploughed and no tillage fields, and described using the profil cultural method and the new indicators. Root maps were also traced to observe the effect of soil structure on root growth. Preliminary results show that the classification of cracking and the quantification of the number of earthworm burrows per m^2 can explain observed root development in subsoil. This first approach towards a better observation of subsoil structure and the effect it has on roots needs to be confirmed through further research, and especially via quantification and scoring of soil structure impact on roots.

1. Introduction

Many soil visual assessment methods exist worldwide to evaluate fertility and soil structure. A field meeting in Estrées-Mons (France) in 2005 was a good opportunity to present and compare several of them (Boizard et al., 2007). Among all these methods, two main types can be distinguished: (i) methods based on the topsoil examination with VESS (Ball et al., 2007), or the VSA drop test (Shepherd, 2000) and (ii) those based on soil profile evaluation (Roger-Estrade et al., 2004; McKenzie, 2001a,b; Batey and McKenzie, 2006). In France, agronomists have studied the effects of cropping systems on soil structure, using the field method based on soil profile called "profil cultural", as it will be referred to hereafter. In this method, the soil structure is observed on a vertical face of a pit (Roger-Estrade et al., 2004). The profil cultural method was devised to understand the effects on soil structure of tillage and compaction caused by the passage of agricultural machinery. It was developed by Manichon (1982) and propagated for agricultural development by Gautronneau and Manichon (1987). In scientific literature, it was described by Boizard et al. (2002) and Roger-Estrade et al. (2004). They demonstrated the relevance of this method in evaluating the effect of cropping systems and tillage techniques on the soil structure of the topsoil. In their studies, photographs and image analysis were used to give a more precise transcription of the observed soil structure (Boizard et al., 2002). This method was also coupled with the observation of root crops in some situations. For instance, Tardieu and Manichon (1987) proposed a method of tracing root maps and showed how effective this method was in studying the effect of topsoil compaction on root growth.

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As the profil cultural method was first devised to evaluate the effect of agricultural operations in ploughed tillage systems, the focus was initially on topsoil. But the profil cultural method also allows us to examine the subsoil (Gautronneau and Manichon, 1987). Permanent soil properties thus provide valuable information on the agronomical potential of soil, for example the volume of soil available for root growth. The objective is to better evaluate (i) the intrinsic properties and agronomical potential of the subsoil and (ii) how the subsoil can be altered by compaction or exploited by the root system. Indeed, studies conducted during the 1980–2000 period established the importance of subsoil compaction which altered soil properties (Akker et al., 2003). Trautner and Arvidsson (2003) showed the intensity of subsoil compaction that could extend to a depth of up to 0.7 m relative to different loads and soil water contents. Boizard et al. (2000) showed the physical and hydraulic properties at a depth of 30–40 cm in the subsoil could be altered significantly after one or two sugar beet harvests in wet conditions. Alakukku (2000) studied the long-term effects of soil compaction created by a single heavy load applied on the soil. This subsoil compaction reduced nitrogen uptake of crops and therefore yields.

The soil layer between topsoil and subsoil is particularly sensitive to compaction. Being relatively close to the soil surface, it can be strongly affected by soil compaction under the wheels of vehicles but also by the action of tools like the mouldboard plough. Given the depth of this soil layer, fragmentation using a soil loosener is a difficult operation and expensive in terms of energy consumption. The soil layer between topsoil and subsoil will be called the "transition layer". It corresponds to the interface between the cultivated soil layer (topsoil) and the part of the subsoil where compaction could occur (Spoor et al., 2003). We propose to adopt this definition, but by limiting the subsoil considered at <10 cm thick. In France, in a ploughed tillage system, multiple reasons may explain the presence and thickness of the transition layer. In systems where the plough depth is constant between 20 and 30 cm, the transition layer may take the form of a thin layer within the layer cultivated, or just beneath. The repeated application of the mouldboard during ploughing is likely to create a plough pan with a soil platy structure. A second case corresponds to the presence of old plough pans, particularly in areas, at least in France, where the soil can be characterized as a deep silt loam. In such areas, farmers frequently ploughed to a depth of up to 40 cm in the 1970–1980 period and now have reduced the tillage depth to between 25 and 30 cm, and some to only 20 cm. Moreover, in no till or reduced tillage systems, where no tillage (no soil inversion and reduced depth of work) is performed from 0 (no till) to 15 cm (reduced tillage) depth, the transition layer is generally still visible but more fuzzy (it may be between 20 and 40 cm deep in the soil). In all these cases, the transition layer could have compacted zones due to the presence of an old plough pan or the tyre pressure of agricultural machinery.

The transition layer has not always been considered in detail in previous studies using the profil cultural method, despite being of major importance in evaluating the effects of cropping systems on potential yield through root growth. For example, the presence or absence of a plough pan, the degree of compaction of the plough pan and the effect this has on subsoil functioning, are essential indicators to understand root penetration and development in the subsoil. Many authors have described the negative effects of a plough pan. As early as 1978, Loon and Van Buma showed compaction resulted in depressed tuber yields at maturity. However, the decision to fragment the transition layer should only be taken after a thorough evaluation of the observed case. According to Spoor et al. (2003), a lightly compacted transition layer which roots, water and nutrients can pass through, is an asset in that it protects deeper subsoil from compaction. The transition layer can be fragmented in part by subsoiling. But this operation is difficult to perform and highly consuming in both energy and time. It could also be fragmented by climatic conditions and earthworm activity, especially in no tillage systems. Shipitalo and Protz (1987) showed that no tillage (no soil inversion and reduced depth of work) induces less total macroporosity than ploughing but more biological porosity. Earthworm burrows, porosity due to root development and cracks are not destroyed by ploughing and thanks to the accumulative effect over time, more biological macroporosity can be found in no tillage soil profiles (Shipitalo et al., 2000).

These observations raise the question of the effect of earthworms on soil structure: does their burrowing activity improve soil porosity, thereby improving rooting? Goss et al. (1984) conclude that ploughed soil contains more macropores, but observe less continuity of these pores in the subsoil compared to no tillage. Total macroporosity may have a less significant effect on rooting than that developed by biological activity or cracks in the subsoil (Shipitalo et al., 2004). McKenzie et al. (2009) showed that a defined number of holes per unit area of soil were able to control access of water to the subsoil. Capowiez et al. (2009) showed the ability of different species of earthworm to burrow through compacted soil layers, leading to the general assumption that soil fauna play a significant role in regenerating compacted volumes in agricultural systems.

There is still a need for methods in field assessment to be better able to quantify biological macropores and crack density, and to assess the degree of hampering caused by a compacted transition layer, such as a plough pan or an old plough pan in no tillage. The assessment of cracks and biological macropores will help advisers to analyze if it is necessary or not to subsoil (Spoor et al., 2003) and also to propose a diagnosis on potential root development, even if no roots are visible when the diagnosis is carried out (first stage of crop development, before crop seeding).

The profil cultural method was first developed on ploughed soils to describe topsoil structure. It was therefore not designed for the thorough study of subsoil and transition layer soil structure, nor to assess the effects of biological activity on soil structure. The objective of this paper is to show that the profil cultural method is able to examine subsoil, and especially the transition layer between topsoil and subsoil. In addition to the standard morphological approach, we propose indicators to integrate the burrowing activity of earthworms and cracks on soil structure. Together, these indicators improve the quality of the assessment as to the agronomical potential of the soil in different cropping systems such as no tillage. Because profil cultural method is time consuming, these additional indicators are intended for improving the understanding of root development potential, rather than for rapid diagnosis.

To test the relevance of the profil cultural method to describe the effects of the soil structure (of the transition soil layer and subsoil) on potential root development, we use soil structure and rooting data from trials comparing no tillage and ploughing system in organic farming.

2. Material and methods

2.1. *Profil cultural method (Gautronneau and Manichon, 1987)*

To fulfil the different objectives of the method, we distinguish three steps. Each step has a specific purpose:

step 1: understanding the effect of agricultural practices, such as tillage, on topsoil structure;
step 2: estimating the agronomic potential of the whole soil profile with a particular focus on subsoil;