ABILITY OF THE "PROFIL CULTURAL" METHOD TO ASSESS THE SOIL STRUCTURE OF UNTILLED LAYERS

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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. The "profil cultural" method (Manichon and Gautronneau, 1987) has been set up to perform a field diagnostic of the effects of tillage and compaction on soil structure. However, this method was developed and mainly used in conventional tillage systems, with ploughing. As several forms of reduced, minimum and no tillage systems are expanding in many parts of the world, it is necessary to re evaluate the ability of this method to describe an interpret soil macrostructure in unploughed situations.
In unploughed fields, soil structure dynamics of untilled layers is mainly driven by compaction and regeneration by natural agents. Amongst them the role of climate and earthworms is essential and it is of major importance to appreciate the natural processes of soil structure regeneration. The "profil cultural" method is based on a visual observation of the macroscopic structure of different zones in the top part of the soil profile. Therefore, the method must be able to take into account the change in soil properties due to the presence of cracks and macropores.
The objective of this presentation is to review the ability of the morphological method to describe the structure of untilled layers. Complementary indicators of biological macropores and cracking are proposed to complete the previous description.

Keywords: soil structure, soil visual assessment, no till, subsoil compaction

1. Introduction

The soil structure of the tilled layer of cultivated fields shows spatio-temporal heterogeneity due to anthropogenic (*i.e.* tillage and compaction) as well as natural processes (*i.e.* climate, root growth and fauna activity). These processes alter the spatial arrangement, size and shape of soil aggregates as well as the inter- or intra-aggregate pore system (Dexter, 1988). However, beyond punctual characterisations, it remains difficult to evaluate the dynamics of changes in soil structure over time. Boizard et al. (2002) showed that the "profil cultural" method is well suited to taking into account the spatial variations of the soil structure caused by tillage, wheeling and weather conditions in plough tillage systems. The change of soil structure over time was evaluated by a field visual assessment indicator referring to the proportion of compacted clods (called Δ) in the tilled layer. This indicator provided a more detailed description of changes in the soil structure over time than the mean soil bulk density. The main advantage of this method is that it takes into account the spatial variations in soil structure caused by tillage, wheeling and weather conditions. However since its development in plough tillage systems in 1982 (Manichon, 1987), its applicability to describe the evolution of soil structure accurately in situations with reduced tillage remains to be seen. In reduced or no tillage cropping systems, soil compaction and its reversibility are major factors. While many studies have focused on the origins behind compaction and its effects (Ball *et al.*, 1997; Smatana *et al.*, 2010), few have dealt with structure regeneration by natural agents such as soil biota, roots and climate,

although these processes are considered essential in reduced tillage (Utomo and Dexter, 1982; Taboada *et al.*, 2004). Weather conditions in particular – through drying-wetting and freezing-thawing cycles – have a marked influence on the formation of soil cracks of various kinds and consequently on the physical and hydraulic properties of the soil (Rajaram and Erbach, 1999). It is thus generally claimed that earthworms can contribute to the regeneration of compacted zones by burrowing through these zones and this was demonstrated under laboratory conditions (Jégou *et al.*, 2001) and in field conditions (Capowiez, 2006). So taking into account of cracks and macropores by the methods of visual assessment is a major issue.
The objective of this presentation is to review the ability of the morphological method to describe the structure of untilled layers in reduced tillage.

2. Materials and Methods

2.1 Description of the method

The morphological analysis of the soil profile is carried out in several steps. The location and size of the pit are chosen so that it is representative of the spatial variability of soil structure in the tilled horizons. The scheme uses a system developed by Gautronneau and Manichon (1987) based on a two-way partition – vertical then lateral – which provides the framework for the description (Figure 1). The different topsoil horizons, which are delimited by the tillage depth of the successive cultural operations, are distinguished first (Vertical stratification). Secondly, a lateral stratification is based on the location of the wheel tracks due to the machinery operations. Hence, compartments are delimited on the observation face of the pit. They are defined by two identifiers such as H5L2. For instance, compartment H5L2 is the compartment of soil that has been loosened at the last ploughing (H5), and has been affected by machinery wheels at secondary cultivation (L2).

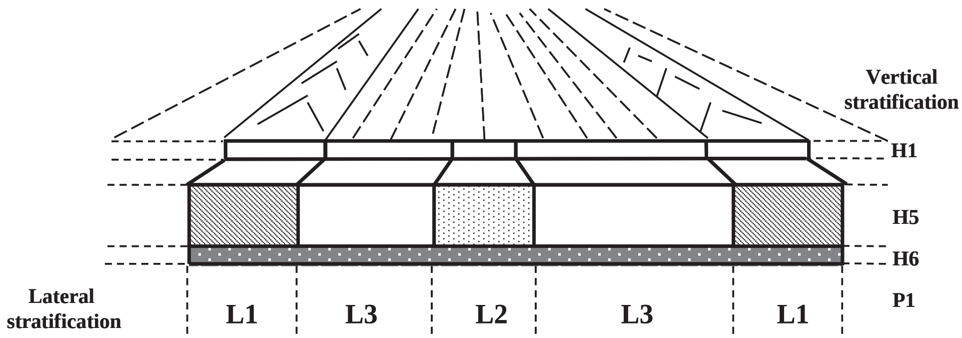

Figure 1. *Principle of the stratification of the observation face of a soil pit. Vertical stratification : H1 = seed bed ; H5 = part of the ploughed layer untilled since the last ploughing ; H6 = part of the ploughed layer located between the last plough pan and a deeper plough pan ; P1 = first untilled layer. Lateral stratification: L1 = part of the profile located under the wheel tracks of field operation(s) done after secondary tillage (visible at soil surface); L2 = part of the profile located under the wheel tracks of field operation(s) at secondary tillage; L3 = part of the profile unwheeled since ploughing.*

The next step is to map the soil structure variations in the tilled layer, describing the structure in each compartment.

The different structure types are identified in the field, using a knife. In this way a particular attention is paid to the most compacted zones, which have specific features such as no visible macropores, a massive structure and a smooth breaking surface. They are outlined in slight relief on the observation face (Boizard et al., 2002).
The soil structure is described using two criteria:
l The spatial arrangement of voids, cracks, organic residues and clods is described for each compartment. According the way the clods are brought together, three structural types are defined: o, b or c (o for an open structure, b for a blocky structure and c for a continuous structure) as defined by Gautronneau and Manichon (1987).
l The zones and clods (> 2cm) inside each compartment are individualized in order to characterize their internal state. Clods are separated in four classes according to their proportion of visible structural porosity and the action of climate and biological activity. Those with a loose structure, exhibiting a clearly visible structural porosity, are called gamma clods (Γ). Those with a

compacted structure, without any visible structural porosity, are called Δ clods. Those which exhibit cracks due to weathering are called Φ (Phi) clods. Lastly, those exhibiting a platy structure are called P clods. An intermediate class called Δ_0 is also proposed and corresponds to an aged Δ state with presence of earthworm's burrows. According to Gautronneau and Manichon (1987) and Roger-Estrade *et al.* (2004), clods can evolve from one internal state to another. Indeed, Tillage tools can fragment Δ clods into fine soil, which could evolve into Γ clod (fragmented). Conversely, wheels can compact fine soil and create Δ clods. Roots and above all climate can modify a Δ clod into a Φ or a P clod. Fauna can transform a Δ clod into Δ_0 by burrowing. To complete the description of soil structure, the impact of earthworm activity on soil porosity can be measured through the presence or absence of macropores related to burrowing (vertical burrows 1 to 3 mm in diameter with anecic species). For instance anecic burrows can be counted at 20 cm depth in the soil pit on a horizontal 0.2 m^2 plane (Peigné *et al.*, 2009; Capowiez *et al.*, 2006). At last, a careful analysis of the structure types and their location in the profile allows a precise analysis of the effect of crop management and soil tillage on soil structure. For example a fragmented soil structure in the compartment L3/H5 ("oΓ in compartment L3/H5") implies an un-compacted structure before ploughing, followed by an intense fragmentation during this operation. Or, a degraded structure in the compartment L2H5 ("cΔ in section L2/H5") reveals a very compacted structure created by the wheeling during secondary tillage.

2.1 Site and soil

The method was tested in the long term experiment "Cropping systems and Soil Structure" in northern France at the INRA experimental centre of Estrees-Mons (Péronne, 50°N latitude, 3°E longitude, 85 m elevation). Three cropping systems were compared between 1989 and 2008 with a wide range of soil compaction intensities, depending on crop rotation and decision-making rules for cropping operations (Boizard et al., 2002). Each crop was grown every year, giving 12 treatments. The experimental design consisted of two blocks (giving a total of 24 0.40 ha. plots) with a ploughed tillage system up to 1999. From 1999 the ploughed tillage system was continued in the first block (CT) and reduced tillage system (RT) was introduced in the second block. In RT the soil was superficially tilled down to 5 cm deep only. The plot size made it possible to reproduce the traffic patterns of machinery found in commercial farms.

The soil was classified as a silt loam (Luvisol Orthic, FAO classification). It contained an average of 190 g clay kg^{-1}, 738 g silt kg^{-1}, 50 g sand kg^{-1}, 17 g organic matter kg^{-1}, 5 g $CaCO_3$ kg^{-1} . The pH is 7.6. Soil water contents at -10, -50, -100 and -1500 kPa were 0.252, 0.213, 0.164 and 0.083 g g^{-1} respectively. The average atmospheric temperature between 1999 and 2006 was 11.1°C and the average annual rainfall was 713 mm. The climate was contrasted during the 2000-2005 years period with especially three successive dry years in 2003, 2004 and 2005. The annual rainfall from 2000 to 2005 was 810, 936, 797, 490, 569 and 578 mm respectively.

3. Results

3.1 Ability of the method to evaluate the soil structure dynamics

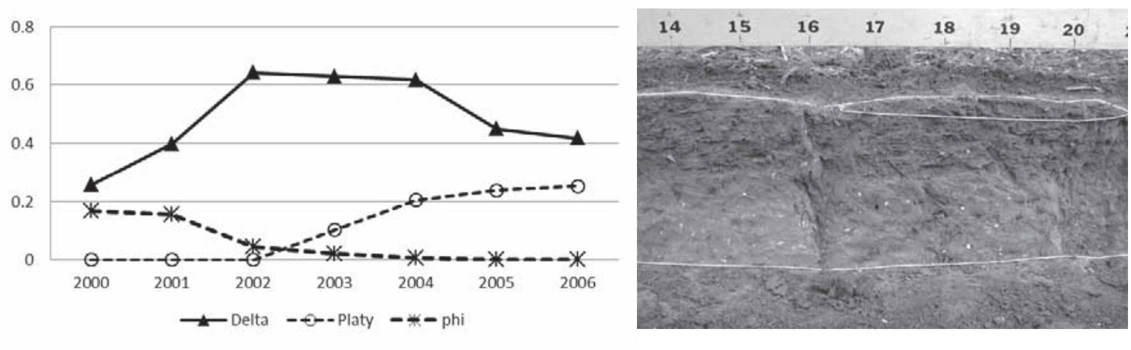

Figure 2: Changes in the proportion of Δ, Φ and P areas over time measured after sowing ($m^2.m^{-2}$) in plot 9. The proportion of Δ, Φ and P areas was calculated in the first thirty centimeters of soil under the seedbed and photograph of the plot with the different morphological units

The "profil cultural" method was carried out every year, after each sowing date, to studying soil structure dynamics in reduced tillage systems. An example of results is given for plot 9, a highly compacted plot(Boizard *et al.,* 2012). The proportion of Δ areas greatly increased in 2002 due to high soil water content during sugar beet harvesting in late autumn 2001 and CI was 0.67 (Figure 2). Little compaction occurred between 2003 and 2006 and the proportion of Δ areas slowly decreased from 60% to 40%. An inverse trend was observed for the platy structure, which was systematically observed from 2003 onwards, with the proportion of P zones reaching a maximum of 23% in 2006.

Thus the visual assessment method allowed a detailed analysis of compaction after each cultivation operation and the evolution of the compacted volumes over time through the description of Δ zones and their localisation and allowed to put into evidence the progressive development of a platy soil structure, which suggests that freezing-thawing or wetting-drying cycles may drive its extension.

3.2 Ability of the method to distinguish morphological units

The "profil cultural method" was developed by Manichon (1987) in ploughed tillage system to map the soil structure variations in the tilled layer. A major issue is to know whether the morphological units correspond to specific and permanent properties. In the same experiment, three soil hydraulic and mechanical properties – infiltration rate, shear strength and penetration resistance – were measured for each structure type (oΓ, cP and cΔ) by taking morphologically uniform soil volumes in the three plots (Boizard *et al.*, 2012). The physical properties of the Γ structure type were also measured in a plot of ploughed tillage treatment (plot 17) to compare the Γ structure type in conventional and reduced tillage.

The results show that the information obtained with bulk density and visual assessment is similar (Table 1). The Γ structure types have the lower bulk density, but the difference in bulk density between tilled and untilled layer is high (1.35 *versus* 1.48). In contrast the difference in bulk density between the oΓ and cΔ structure types is low (1.48 *versus* 1.55). Results also showed that soil properties evolved simultaneously with soil structure changes. Resistance in penetration and shear strength was higher in the Δ structure types. But shear strength decreased with platy soil structure development because horizontal cracking introduced planes of weakness, while vertical penetration resistance remained unaffected.

Table 1: Bulk density, shear strength, resistance to penetration and infiltration rate measured for each structure type

Structure types	Bulk density		Shear strength (kPa) at 0.18 SWC		Resistance to penetration (kPa) at 0.19 SWC		Infiltration (mm/h) at 0.18 SWC	
			Mean value		Mean value		Mean value	
Control	1.35	a	33	a	1319	a	549	a
oΓ	1.48	b	52	bc	2905	b	284	b
cP	1.58	c	44	b	4518	c	86	c
cΔ	1.57	c	57	c	5211	cd	65	c
cΔ	1.55	c	55	c	5340	d	58	c
P value	0.001		0.001		0.001		0.001	

33 Ability of the method to evaluate macropores numbers

To study the ability of earthworms to regenerate soil structure after compaction, an experimental compaction event was carried out in a plot of the long term experiment (Capowiez *et al.*, 2009). The number of macropores was evaluated in compacted and uncompacted zones five times over a two years period.

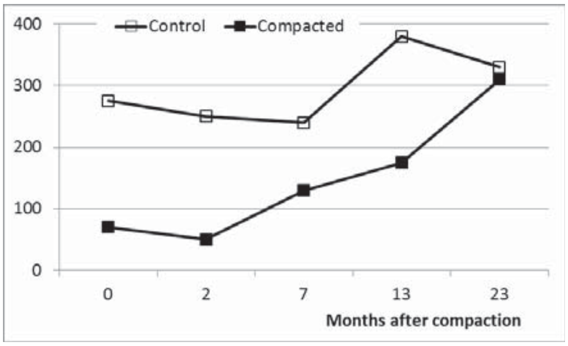

Figure. 3. Number of macropores > 2 mm per m^2 at each sampling dates in under wheel tracks (compacted) and between wheel tracks (control) for two pore size classes.

The mean number of macropores in the compacted zones increased with time from 75 to 310. In the control zone, the number of macropores was fairly constant for both classes of pores. These results show the proposed criterion was able to follow the evolution of macropores following a severe compaction.

3. Discussion and conclusion

The results shows that the "profil cultural" method appears well suited to taking into account the spatial variations of the soil structure caused by tillage, wheeling and weather conditions in reduced tillage system. Used in the long term experiment, the morphological approach allowed a detailed analysis of compaction at each cultivation operation and change in the compacted volumes over time through the description of compacted zones and their localisation. The proposed structure states corresponded to differences in porosity or physical properties. Compared to the analysis of porosity, it must be noted that the low difference in porosity between the oΓ and cΔ structure types was revealed with the visual method, while such small differences can be put into evidence only thanks to a major effort of measurements. Guerif *et al.* (1994) showed that the Δ structure has permanent properties, such as high resistance to penetration, whatever the soil type or geographical situations. Our results show the observed structure states corresponded to differences in porosity or physical properties, but it remains to verify that these properties are permanent in a wider range of situations

Cracks and the macropore network play an important role in the functioning of the soil and root access to the subsoil (McKenzie et al., 2009). The visual method allowed putting into evidence the progressive development of a platy soil structure, but a micro-morphological assessment was performed to get detailed information about the network of cracks (Boizard, 2012). The micro-morphological characterisation showed that a visual morphological approach was insufficient for revealing the entire network of cracks. On the other hand, the description of the number of macropores on a horizontal 0.2 m^2 plane was efficient but time consuming. A major challenge in being able to model the long-term structural dynamics in reduced tillage systems is to characterise cracks and the macropore network more effectively.

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