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The numeric visual evaluation of subsoil structure (SubVESS) under agricultural production

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ABSTRACT

Subsoil degradation in agriculture is an increasing problem worldwide, particularly due to compaction caused by heavy machinery. Here, we describe a numeric assessment of subsoil structural quality in relation to soil as a crop growth medium and illustrate its utility with results from compaction experiments and from fields under minimum tillage. The scoring scheme resembles the topsoil visual evaluation of soil structure (VESS) (Guimarães et al., 2011) with more emphasis on examination of the profile wall and of soil fragments. The focus is on identification and evaluation of the anthropic 'transition layer' immediately below the topsoil, usually >30 cm depth. Layers of contrasting hardness and colour were identified and the overall subsoil quality of each layer was scored from separate, sequential assessments of soil mottling, soil strength, visible soil porosity, the pattern and depth of root penetration and aggregate size and shape using a colour diagnostic flowchart. Use of the method enabled identification of extent and severity of compact transition layers in both well-drained and imperfectly drained soils. Porosity and strength assessments were particularly relevant. Reference soils under forest or long-term grassland helped to distinguish whether subsoil structural quality resulted from the natural soil composition or from degradation by land management. The derived scores may be used to judge the requirement for amelioration by subsoil loosening by mechanical inputs (e.g. deep tillage) and/or natural processes (e.g. shrinkage crack formation). The method was also used to identify differences in subsoil structural quality within fields associated with field traffic levels (Oxisol in Brazil) and with moisture status (Luvisol in France). The focus of SubVESS on structure rather than on texture may not permit recognition of effects such as low water holding capacity that influence agronomic potential. In such cases the more comprehensive evaluation of overall agronomic potential by methods such as the 'profil cultural' is required.

1. Introduction

The subsoil is highly important for the storage of plant available water, particularly in semi-arid regions or in areas with frequent water shortages, and for the conduction of water and air, particularly in humid areas where drainage of excess rainfall is required. It also stores nutrients for plant growth. The subsoil regulates rooting depth and is seen as increasingly important for storing recalcitrant carbon (Lorenz and Lal, 2005). The subsoil structure may influence the suitability of the topsoil for tillage through its influence on the water status of the soil (Mueller et al., 1994). Lying between the topsoil and parent material, the development of structure in the subsoil is predominantly physical through the processes of drying and wetting, freezing and thawing. The concentration of soil organic matter (SOM) is low and fed by the entry of roots and their subsequent decomposition. Subsoil structure tends to be stable and soil organic matter neither features in its development nor in its stability as it does in the

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topsoil. Exceptions include sodic subsoils that can disperse and then be prone to tunnel erosion (So and Aylmore, 1993) or soils with spodic B horizons where there is accumulation of organic matter and Fe/Al oxides/hydroxides (Petersen, 1976).

Where the emphasis is on pedology i.e. the morphology and genesis of soils, subsoils are normally described in considerable detail during soil profile description. Such methods include the FAO standard for the World Reference Base for Soil Resources (FAO, 2006), general soil surveying (Hodgson, 1974 in the UK; NCST, 2009 in Australia) and land evaluation and soil management (Batey, 2000). More recently the increasing influence of human activity leading to soil degradation such as salinisation, disturbance (e.g. by mining or pipeline installation; Batey, 2014) and compaction by machinery has led to the need for a functional evaluation of the subsoil. Conventional pedological methods are insufficient to detect management-induced differences in soil, particularly in the upper subsoil where human activity such as compaction or deep tillage can transform the structure of the soil; descriptors that are more relevant to crop yield potential are required (Mueller et al., 2012). If the soil in its natural condition is considered to be the 'genoform', then 'phenoforms' with differing soil indicators can subsequently develop according to management practice (Droogers and Bouma, 1997). Since compaction and tillage principally influence structure, emphasis is on the assessment of subsoil structure such as SOILpak for cotton growers (McKenzie, 1998), 'le profil cultural' for soil management (Peigné et al., 2013) and morphological descriptions for water management in wet soils (Mueller et al., 1994). Detailed tests of the potential of the soil for crop productivity already exist. The rating scheme of Mueller et al. (2012) uses a combination of hazard and potential indicators to give an overall assessment of soil quality at the national or trans-national scale. The scheme of McKenzie (2013) operates at the field scale.

Subsoil compaction is one of the major threats to future crop productivity because farm machinery is becoming heavier and is used more frequently in unsuitable conditions. Thus, large areas of Europe are vulnerable to degradation (Jones et al., 2003). In tropical and sub-tropical areas of developing countries, the increase of size and weight of agricultural machinery also increases the risk of subsoil compaction, particularly in the upper subsoil. In parts of the world where climate change results in increased rainfall, the risk of damaging effects of compaction in both topsoil and subsoil will increase. Visual assessments have proven valuable in detecting compaction with emphasis on the upper soil layers (Guimarães et al., 2011,b; McKenzie, 2001a,b). Subsoil assessment is also important for the determination of the permeability of clay subsoils (Swarz et al., 2003).

Descriptions of topsoil structure and subsoil structure are not identical. Many of the methods developed for visual assessment of topsoil attach great importance to compaction status. However, the bulk density of subsoil can be high initially for some types of soil, and consequently the increase in bulk density is possibly small. For example, Arvidsson (1998) showed that the increase of bulk density in Sweden was only 0.00–0.13 $Mg\,m^{-3}$ after 4 passes with a sugar beet harvester weighing 38 t. Boizard et al. (2000) also showed a significant effect of cropping systems on subsoil compaction in the Estrées-Mons long term experiment. However, the change in bulk density was very small (0.01–0.04 $Mg\,m^{-3}$) even though the penetration resistance increased significantly and the hydraulic conductivity decreased sharply after compaction. They deduced that the network of cracks and macropores facilitating vertical transfers of air and water should be better taken into account.

The rapid numerical assessment of subsoil structure is thus a priority and the systematic and careful examination of the subsoil is to be encouraged. The Visual Soil Examination and Evaluation Working Group of ISTRO recognised this at their meeting in Peronne in 2005 and further encouraged its development at their next meeting in Flakkebjerg in 2011. Subsoil structure classifications, e.g. Mueller et al. (1994) mainly depend on the description of component aggregates or lumps of soil with emphasis on the shapes of aggregates or lumps and the presence and shape of pores and cracks. We take a similar approach, but integrate information on rooting, colour and biotic activity. A visual key is included to help identification of limiting layers in a method similar to that used in developing the VESS (Ball et al., 2007). We decided to adopt a separate scoring scheme from the VESS as conditions are clearly different in the subsoil where the scale is greater and there is more emphasis on profile wall investigation and examination of soil fragments. In our approach to assessing soil structural quality we broadly followed the four fundamental aspects of soil structure identified by Kay (1997) as form, stability, resilience and vulnerability, with emphasis on form. We propose a numeric assessment of subsoil structural quality in relation to soil as a crop growth medium and illustrate its utility with results from compaction experiments.

2. Development of the evaluation

The test has been designed as a rapid method for practitioners with some soils knowledge in order to evaluate whether the management practices in use by farmers have resulted in soil damage. It can also be used to assess compaction damage in land disturbed during surface mineral extraction, the installation of cables or pipelines, or after landscape re-shaping. A further objective was to indicate from the profile the depth and thickness of layers where remedial operations can be targeted. With some training, non-soils experts should be able to use the system. The emphasis is on how the intrinsic potential of the upper subsoil (~30–60 cm) has been reduced with a view to identifying remedial work in relation to overall land capability. Our proposed method is thus less detailed than those used for the comprehensive examination of the physical properties of subsoils in formal surveys of soils.

Nevertheless, it is important to assess those properties that determine the inherent capability of the soil as a whole. Much of this capability relates to the abilities of the soil to supply water to the crop and to allow good drainage. This is related to texture and to the content of coarse fragments in the root zone. We realise the importance of texture in influencing the function of soil structure. For example, in subsoils dominated by sand, root penetration may be poor without obvious signs of compaction or hardness (Batey, 2000). Also the development of shrinkage cracks is a major process in clay soils and depends on the soil moisture deficit and on the type and content of clay (Batey, 2000). The effect of weather conditions on producing cracking can also be effective in soils of coarser texture as demonstrated by (Boizard et al., 2013) in a silt loam of about 19% clay content.

In addition to cracking, Peigné et al. (2013) stressed the importance of quantification of earthworm macropores. McKenzie et al. (2009) buried a mesh layer horizontally in the soil so as to prevent root penetration to the subsoil. The mesh was punctured to create a defined number of holes per unit area. Results showed that crops grown with controlled, limited access to the subsoil performed better than those with no access and the performance was generally related to amount of access. So it is important to have visual evaluation that is able to reveal channels and cracks. The evaluation of the current state of the soil and how this might be improved here are based on visual and tactile soil structural quality assessment.