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Contrasted effects of no-till on bulk density of soil and mechanical resistance

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ABSTRACT

Compaction caused by traffic, results in degradation of soil structure with possible agronomic and environmental consequences. On the other hand, no-till systems have a great impact on soil structure and can improve their mechanical resistance. This property is described by compression curves using two parameters: the precompression stress P_c and the compression index C_c. Both mainly depend on bulk density, water content and soil texture. We aim to study the effect of farming practices on bulk density and mechanical resistance and also on the relation between those two properties in order to define diagnostic tools on the lasting effect of practices. Unsaturated soils were used, since cohesion is mainly attributed to capillary forces, themselves structure-dependent. "Equilibrium states" of soil structure corresponding to a fixed matric potential value, are then compared at various bulk densities. Pedo-tranfer functions (PTF) were defined by the relationship between P_c, C_c and the initial void ratio (e_0). Soils originated from two long-term experimental sites: Versailles and Boigneville (France), where till and no-till systems are being compared. PTF have been established from remolded samples taken in till systems using a large range of e_0 values. The effect of practices has been measured through mechanical properties of undisturbed soil cores. Uniaxial compression tests were performed in laboratory in drained conditions. In till systems, the global shape of compression curves varies for remolded cores from an S-shaped model to a rounded shape when e_0 decreases, followed by a bi-linear one. C_c appeared simply proportional to e_0 in all soils due to the progressive water saturation of soil core at inflexion point, when e_0 decreases. For intact cores coming from till systems, this PTF should reveal heterogeneities and variability in soil structure. According to this PTF, there is no effect of practices in field. On remolded samples and till system, P_c was mostly constant in Versailles while P_c did strongly increase when e_0 decreased in Boigneville, due to progressive saturation of porosity. Effects of no-till were contrasted among soils and shape of curves. In Boigneville, mechanical resistance deduced from bi-linear curves increased as it decreased with S-shape curves and lead to a global increase in e_0 values. The opposite was observed in Versailles soils probably due to the opposite change induced by no-till in soil–water–air interaction among soils. The original approach developed is therefore relevant to study other soil, climates, land uses and plants.

1. Introduction

Soil is a non-renewable resource, which needs to be sustainably managed (Kibblewhite et al., 2008), in order to prevent their physical degradation by erosion and compaction (Horn, 2009). Compaction due to agricultural practices (farm traffic, soil tillage, short rotation, etc.) results in soil structural degradation and reduced physical qualities, inducing both agronomic and environmental consequences (Soane and van Ouwerkerk, 1994). Compaction can change the fate and ecotoxicological impact of organic contaminants for instance (Mamy et al., in press). Soil compaction affects a large area of agricultural soils in Europe (Hamza and Anderson, 2005).

No-till and conservation tillage affect physico-chemical properties of soils such as bulk density, aggregation, hydraulic conductivity, pH, and organic content. This even if the effect on soil health is still unclear with sometimes contradictory effects (Alvarez and Steinbach, 2009; Bronick and Lal, 2005; Carof et al., 2007; Daraghmeh et al., 2009; So et al., 2009; Strudley et al., 2008). Those tillage practices can be useful alternatives to traditional tillage to reconcile production and environmental protection interests. The effect of practices on soil behaviour happens mainly

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through changes in soil structure (Bronick and Lal, 2005). Mechanical properties of soils are related to their structure mainly through bulk density values, topology of the porosity and water content; itself dependent upon soil structure. A better understanding of these relationships would help to define diagnostic tools on the lasting effect of farming practices.

1.1. Mechanical properties of soils

Mechanical resistance is the ability of a soil sample to resist deformation when subjected to an external force. Mechanical resistance is described by the compression characteristics that show the relationship between stress applied on a soil sample and volumetric parameters such as strain, void ratio or porosity. Compression curves have two principal mechanical parameters: (i) the pre-compression stress P_c as an indicator of the soil's load support capacity and (ii) the slope of the virgin compression line VCL, namely compression index C_c. Compression curves mainly depend on bulk density, water content, texture, organic carbon; those physical properties being closely related. The close relationship between those parameters and the diversity of experimental settings account in part, for the contradictory results found in the literature concerning the impact of water content on mechanical properties (Cui et al., 2010).

In unsaturated granular medium, cohesion is mainly due to capillary effects. It increases with relative moisture by creation of liquid bridges and meniscus, to reach a maximum and then decrease past a given saturation rate of porosity. At pore scale, the intensity of capillary forces related to the presence of a water bridge between two beads depends on one hand on liquid properties: water volume in the water bridge, and surface tension and on the other hand on geometrical properties: size of beads, distance between two beads (Halsey and Levine, 1998; Soulié et al., 2006). At macroscopic scale, mechanical behaviour is governed by water repartition inside the granular material that is related to the packing structure, itself related to the polydispersity of beads. Capillary effects in soils are related to their texture and also to the aggregation of the clay fraction. Indeed capillary forces between two clay aggregates assimilated to irregular porous spheres are the same as that of a granular medium. The difference comes from the water volume required first to saturate clay aggregates and second to form a capillary bridge (Sala and Tessier, 1993). Taking further the analogy with granular materials, we can sum up saying that the size of beads is governed by the texture and the aggregation of soils, the same way the distance between beads is mostly governed by bulk density.

Variation in mechanical resistance has been linked to dry bulk density and initial water content using measurements in remolded soil samples (Saffih-Hdadi et al., 2009). Results gave good linear regressions between P_c, C_c and bulk density for various contrasted textures. Using representative undisturbed soil cores to evaluate the effect of practices requires the knowledge of the initial water content and bulk density, because both parameters influence the P_c values. The initial water content of soil samples at the beginning of a compression test may correspond to the water content in field at the time of collection (Cavalieri et al., 2008; Keller and Ardvidsson, 2007; Mosaddeghi et al., 2003). Variability in initial soil moisture among cores of various bulk densities is sensitive to practices (Lebert and Horn, 1991; Peng et al., 2004; Veenhof and McBride, 1996). This variability could contribute to the variation in mechanical behaviour with the initial value of void ratio, e_0 (Lafond et al., 1992). This variability can be translated by a sometimes complex relationship between density and water content, which varies with the weather situation at sampling time due to the hysteresis between drying and wetting of soils. As a consequence poor correlations were obtained between P_c and e_0 (Mosaddeghi et al., 2003). The initial water content of undisturbed cores may also correspond to a given water matric potential imposed in the lab as an equilibration step after collection. Mechanical resistance was measured in many different soils using this experimental procedure. But again no significant correlations were found between P_c and other physical parameters such as bulk density (Arvidsson and Keller, 2004). Most results obtained using geotechnics show that for a given bulk density, C_c decreases in conjunction with an increasing matric potential (Cui et al., 2010).

1.2. Water content and soil structure

For a given soil, an increase in density acts on total porosity and its topology by increasing the number and relative volume of pores of little dimensions, and the reverse for macro-pores (Hill and Sumner, 1967). The soil moisture is influenced by the structure of soil. The relationship between soils structure, described by the bulk density, and water content strongly depends both on the matric potential and on soil texture, where pF is the logarithm of the negative matric potential expressed in cm (Bruand et al., 2004; Groenevelt and Grant, 2004; Hill and Sumner, 1967; Schofield, 1935).

Using silty soils at given matric potential, the water content can (i) decrease with density showing that the reduction in total porosity becomes the dominant feature and (ii) maintain constant or increase according to the contribution of clay and sand fractions (Bruand et al., 2004). For a given soil, this relationship is influenced by the value of matric potential. Opposite effects of bulk density on water content can be obtained at low or high pF (Bruand et al., 2004; Richard et al. 2001). However, in any case the water saturation increases with bulk density up to a maximum according to the magnitude of gravitational flow. For a given water content, again the relationship between the matric potential value and bulk density becomes texture dependent and for a given soil it also depends on the water content value. For high water content, the matric potential decreases following a no-linear function when density increases. The main effects are observed at high bulk density values close to water saturation (Box and Taylor, 1962; Bruand et al., 2004; Hill and Sumner, 1967).

Retention curves describe the water content at given matric potential (Gupta and Larson, 1979). They are described considering a bimodal distribution of pores (Dexter et al., 2008). Interfacial tension must also be considered as it leads to water films in interaction with solid walls, this in addition to capillary meniscus. The first is linked to surface properties and specific surface, the second is related more to the topology of porosity (Bachmann and van der Ploeg, 2002). Linear PTF functions are established for different textural classes considering the reverse of bulk density and cationic exchange capacity, CEC, in order to describe the capillary effects on one hand and the affinity of solid surfaces for water on the other (Bruand et al., 1996, 2004).

1.3. Heterogeneity in soil structure

Heterogeneity in soil structure, especially soil porosity, was attributed to particle aggregation: e_0 was written as the sum of textural and structural components. Textural void ratio represented the arrangement of elementary particles while structural void ratio described macroporosity between aggregates. Structural pores collapsed under compaction, but textural pores were not affected (Bruand and Cousin, 1995; Richard et al., 2001). A slight increase of C_c and an exponentially decrease of P_c with the structural void ratio were found with a loamy soil (Pereira et al., 2007). Heterogeneity in soil structure was also attributed to the presence of biopores. Recent experiments indicated that biopores could resist to compaction, when other pores collapsed (Schäffer et al., 2008a,b). The dynamic of such heterogeneity causes concern, as