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Effects of soil deformation on clay dispersion in loess soil

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ABSTRACT

Clay dispersibility is a good indicator of the vulnerability of soil to disperse and therefore of the associated risks of soil water erosion and crusting and subsequent losses of agricultural chemicals in overland flow. The aim of this study was to determine the effect of soil deformation of an erodible soil derived from loess (Haplic Luvisol) on the content of dispersible clay. The soil deformation levels were: non-compacted (NC, 0 tractor pass), moderately compacted (MC, 3 passes), and strongly compacted (SC, 5 passes). The amount of readily-dispersible clay (RDC) was determined using a Hach 2100AN ratio turbidimeter, by measurement of the turbidity of a suspension of soil in water.

All the measurements were done with soil from the plough (5–20 cm) and subsoil (25–35 cm) layers. The amount of RDC increased with increasing deformation level and depth. In the plough layer this increase was from 0.786 under NC to 1.216 g 100 g^{-1} under SC. Corresponding values in the subsoil layer were 1.227 and 1.874 g 100 g^{-1}. Positive correlations were found between readily-dispersible clay and bulk density in both the plough ($R^2 = 0.685$) and the subsoil layers ($R^2 = 0.332$). The results for clay dispersion are discussed in relation to the different contents of organic carbon in the plough and subsoil layers and the potential mechanisms of soil vulnerability to soil erosion, crusting and deformation.

1. Introduction

The fraction of clay that disperses in water is known as water-dispersible clay (Dexter and Czyż, 2000; Igwe and Udegbunam, 2008). Dispersive soils are common problematic soils in many parts of the world (Dexter et al., 2011; Turgut et al., 2017; Farahani 2018a,b). Clay dispersibility results in the disruption of soil stability and fragmentation (Arthur, 2013; Abdollahi et al., 2014; Farahani et al., 2018a,b), restricted water infiltration and movement and enhanced soil water erosion (Kjaergaard et al., 2004; Panagos et al., 2015; Turgut et al., 2017). Dispersed clay particles are often transported towards water reservoirs carrying nutrients, including phosphorus and contaminants like pesticides and PAHs (Schjønning et al., 2009; Koch et al., 2016) that afterwards contribute to harmful algal blooms (HABs) and environmental pollution.

Clay dispersion and colloid leaching affect metabolic process in soil and can destroy irrigation systems by clogging and can cause the failure of earth dams by erosion (Richards and Reddy, 2007; Rengasamy et al., 2016). Upon drying, however, enhanced clay dispersibility results in unfavourable cementation of soil aggregates (Arthur, 2013), surface crusting and hardsetting soil behavior (Dexter, 2004; Igwe et al., 2006) that impede or stop root growth and shoot emergence (Baumhardt et al., 2004; Daniells, 2012). Many recent studies have focused on clay dispersion and soil structure in response to chemical soil characteristics in relation to soil amendments and tillage practices. Research showed that higher clay dispersion was accompanied by lower pH, content of Ca^{2+}, exchangeable acidity, cation exchange capacity (Igwe and Udegbunam, 2008) and higher concentration of dissolved salts and monovalent cations such as sodium and potassium (Voelkner et al., 2015; Turgut et al., 2017; Rengasamy et al., 2016). More recent studies have shown that the effect of increasing potassium concentration on dispersible clay can be positive or negative depending on soil type and clay mineralogy (Farahani et al., 2018a,b). In general, the effect of the physicochemical and chemical factors on clay dispersion was more pronounced in fine- than in coarse-textured soils (Igwe and Udegbunam, 2008; Voelkner et al., 2015).

Tillage operations and other inputs of mechanical energy to soil especially under wet conditions increase the amount of dispersible clay (Watts et al., 1996; Czyż and Dexter, 2015; Getahun et al., 2016; Gajda et al., 2018; Stanek-Tarkowska et al., 2018). This is because soil

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particles can be moved relative to each other which can break any bonds that were holding them together. This results in the disruption of soil structure, decreased soil friability (Schjønning et al., 2007, 2012) and high soil tensile strength thereby reducing the quality of the soil tilth (Abdollahi et al., 2014). The negative effects can be alleviated by management practices such as diversified crop rotation, manure application and organic farming (Dexter and Czyż, 2000; Schjønning et al., 2007; Gajda et al., 2016) that induce clay stabilization through increase of organic matter content. These examples show that the amount of readily-dispersible clay (RDC) is indicative of the vulnerability of soils to disperse following different soil management practices (Voelkner et al., 2015). Schjønning et al. (2007) reported that changes in clay dispersibility in response to management practices were noticeable before those in soil mechanical behaviour.

Only a few studies, however, have been devoted to the effect of soil deformation on clay dispersibility despite its global occurrence and significance. The initial studies by Schjønning et al. (2007, 2009) showed that traffic by medium-sized tractors caused a minor increase in clay dispersibility even when measured some months after the wheeling. This suggested that further studies are needed, especially in loess-derived soils that are fertile and at the same time prone to deformation (Horn and Fleige, 2003; Zink et al., 2011) and erosion (Fullen and Catt, 2004; Rejman, 2013) and occur in different regions of the world.

We hypothesised that forces exerted during soil deformation by agricultural machinery and associated changes in pore structure affect clay dispersion and mobility. The aim of this study was to determine the effects of different intensities of deformation on the contents of dispersible clay in plough and subsoil layers of loess-derived soil.

2. Materials and methods

2.1. Soil and deformation treatments

The study was carried out on Haplic Luvisol developed from loess, over limestone at the experimental field of the Lublin Agricultural University in Felin (51°15′N, 22°35′E), in the south-eastern part of Poland. Long-term annual mean temperature and precipitation at the site are 7.4 °C and 572 mm, respectively. Some characteristics of the soil are given in Table 1. The soil has a somewhat greater content of particles < 0.002 mm and less organic carbon content at 25–35 cm than at 5–20 cm. Particle density and pH are comparable in both layers.

Soil management history of the site involved crop rotation with cereals (barley and wheat), root crops and legume crops under conventional tillage including pre-plough (10 cm depth + harrowing, and mouldboard ploughing (20–25 cm depth). The soil deformation due to wheeling by a tractor (3.4 Mg) with a contact area stress of 135 kPa and a rear axle load of 22.6 kN included the following treatments: non-compacted control (NC), moderately compacted (MC with 3 passes), and strongly compacted (SC with 5 passes). Uniform wheeling on 30 m^2 plots was performed at a soil water content of 18.5% w/w (soil water potential of −30 kPa) in April 2006 before planting of soybean (*Glycine max* (L.)) cultivar Aldana (since 1992 in the Register of Original Cultivars). Soil samples for measurements of clay dispersion were taken from the plough (5–20 cm) and subsoil layer (25–35 cm) for each treatment three weeks after the wheel passes.

Table 1
Properties of the of the Haplic Luvisol derived from loess[a].

Soil layer (cm)	Clay	Silt	Sand	C org	Total N[b]	P[c]	K	Mg	pH	Particle density
	g kg^{-1}					mg kg^{-1}			H_2O	Mg m^{-3}
5–20	70	290	640	14.1	0.75	90	153	23	5.9	2.61
25–35	130	280	590	2.9	0.23	42	32	35	6.0	2.62

[a] From Siczek et al., 2015, [b]as indicated by the Kjeldahl method, [c]plant available inorganic P.

The dispersibility of clay from soil into water was evaluated by measurements of the concentration of readily-dispersible clay (RDC) made with a Hach 2100 A N ratio turbidimeter. The measurements were made in Nephelometric Turbidity Units (NTU/g L^{-1}) according to Dexter et al. (2011). The values were converted into absolute contents of RDC (g (100 g soil)$^{-1}$) using a calibration coefficient. Bulk density was determined in 100 cm^3 sampling cylinders after drying the soil at 105 °C to constant weight. Four replicates of both variables were used for each compaction treatment in the plough layer and two replicates in the subsoil layer. Additionally, soil samples were taken from headlands including four replicates from the plough layer and two from the subsoil layer. The replicates from headlands were used to determine the relationship between RDC and bulk density. The total number of replicates was 16 for the plough layer and 8 for the subsoil layer.

Grain size is classified as clay if the particle diameter is < 0.002 mm. Soil scientists usually consider the separation to occur at a particle size of 2 μm, sedimentologists often use 4–5 μm, and colloid chemists use 1 μm. Please see more in: Lewis and McConchie (1994).

3. Results

The experimental results presented in Fig. 1 show that the content of readily-dispersible clay was lowest under NC in the plough 0.786 g 100 g^{-1} and subsoil 1.227 g 100 g^{-1} layers and increased gradually in compacted soil. The increases under MC and SC were respectively 23% and 55% in the plough layer and 46% and 53% in the subsoil layer. With all deformation treatments the RDC was greater in the subsoil than in the plough layer.

Fig. 2 shows a positive correlation between the content of readily-dispersible clay and the bulk density. The correlation was stronger in the plough (R^2 = 0.685) than in the subsoil layer (R^2 = 0.332).

4. Discussion

The observed increase in content of dispersible clay with increasing soil deformation level in the plough layer can be caused by compressive and shear forces during traffic (Schjønning et al., 2007, 2012). It is worth of noting that deformation in our study resulted in an increase of readily-dispersible clay by 23–53% and that this is more than in the study of Schjønning et al. (2007) where this percentage was 4–12%. The different increments can be due to the longer period between the soil deformation event and RDC determination in the study of Schjønning et al. (2007) being several months compared to three weeks in our study and also different soil type and compaction levels. Further studies are required to clarify how clay dispersion depends on soil type,

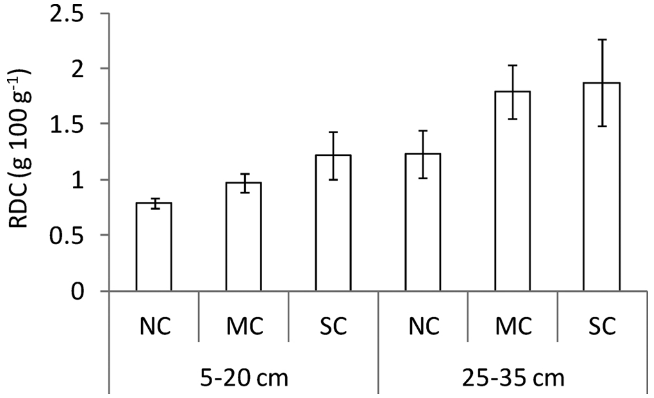

Fig. 1. Content of readily-dispersible clay, RDC, (g (100 g soil)$^{-1}$), for plough (5–20 cm) (n = 4) and subsoil (25–35 cm) (n = 2) layers under different deformation treatments (NC: no compaction, MC: medium compaction, SC: strong compaction). The bars represent the standard error of the mean.