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Soil organic matter widens the range of water contents for tillage

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ABSTRACT

The effects of soil organic matter on the water contents for tillage were investigated by sampling soils with a uniform texture, but a range of soil organic carbon (SOC) from two long-term field experiments at Highfield in Rothamsted Research, UK and Askov Experimental Station, Denmark. The treatments studied in Highfield were Bare fallow (BF), Continuous arable rotation (A), Ley-arable (LA) and Grass (G); and in Askov: unfertilized (UNF), ½ mineral fertilizer (½ NPK), 1 mineral fertilizer (1NPK), and 1½ animal manure (1½AM). Minimally disturbed soil cores (100 cm^3) were sampled per plot in both locations from 6 to 10 cm depth to generate water retention data. Soil blocks were also sampled at 6–15 cm depth to determine basic soil properties and to measure soil aggregate strength parameters. The range of soil water contents appropriate for tillage were determined using the water retention and the consistency approaches. SOC content in Highfield was in the order: G > LA = A > BF, and in Askov: 1½ AM > 1NPK = ½NPK > UNF. Results showed that different long-term management of the silt loam Highfield soil, and fertilization of the sandy loam Askov soil affected the mechanical properties of the soils— for Highfield soil, aggregates from the G treatment were stronger in terms of rupture energy when wet (−100 hPa matric potential) than the BF treatment. As the soil dried (−300 and −1000 hPa matric potentials), soil aggregates from the G treatment were relatively weaker and more elastic than the BF soil. Our study showed, for both Highfield and Askov soils, a strong positive linear increase in the range of water contents for tillage with increasing contents of SOC. This suggests that management practices leading to increased SOC can improve soil workability by increasing the range of water contents for tillage. We recommended using the consistency approach over the water retention approach for determining the range of water contents for tillage because it seems to give realistic estimates of the water contents for tillage.

1. Introduction

Tillage plays an important role in arable farming. One of the primary purposes of tillage is for seedbed preparation, where operations are designed to alter soil bulk density, aggregate size distribution and other soil physical characteristics to create soil conditions and environment favoring crop establishment, germination and growth (Johnsen and Buchle, 1969).

Tillage can be performed over a range of water content ($\Delta\theta_{RANGE}$) where soil is workable. In this study, soil workability is defined as the ease of working with a well-drained soil to produce desirable seedbeds (Dexter, 1988), i.e. not consisting of fragments that are either too fine or too coarse for crop establishment. $\Delta\theta_{RANGE}$ is the difference between the wet tillage limit (θ_{WTL}) and the dry tillage limit (θ_{DTL}). θ_{WTL} and θ_{DTL} are the upper and lower water contents for tillage, respectively. Optimum water content for tillage (θ_{OPT}) is the water content where tillage produces maximum number of smaller fragments and minimum number of large fragments (clods) (Dexter and Bird, 2001). Russell (1961) suggests that small soil fragments that create ideal seedbeds as those consisting 1–5 mm in size. The water contents for tillage have been estimated using the water retention approach (e.g., Dexter and Bird, 2001) and the consistency approach (e.g., Munkholm et al., 2002).

Performing tillage when soil is too wet can lead to structural damage due to remolding and puddling (Dexter and Bird, 2001). Likewise, executing tillage when soil is too dry requires high specific energy because soil is strong (Hadas and Wolf, 1983). Therefore, knowledge of θ_{WTL} and θ_{DTL} and the effects of soil physical properties on these limits are crucial. Such knowledge can provide practical information on the satisfactory $\Delta\theta_{RANGE}$ over which tillage operations produce desirable soil structures for crop establishment and growth (Obour et al., 2017).

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Further, knowledge of the suitable water contents for tillage can be used in a decision support system to reduce the risk of structural damage, and the use of excessive energy during tillage (Sørensen et al., 2014).

Soil organic carbon content (SOC) is a critical soil property that affects many other soil physical properties and functions. Organic binding agents such as roots and fungal hyphae play an important role in soil aggregation and stabilization (Tisdall and Oades, 1982), and improves soil resistance and resilience to external stresses (Gregory et al., 2009). SOC also affects soil mechanical properties such as soil strength, bulk density, inter-aggregate or structural porosity, and enhances better soil fragmentation during tillage (Abdollahi et al., 2014). It also influences infiltration, drainage and water storage — it improves water retention due to high absorptive capacity for water (Murphy, 2015), and increases soil strength in wet conditions, which increases θ_{WTL}. In soils with small content of SOC, clay dispersion is higher (Watts and Dexter, 1997; Jensen et al., 2017), which may increase soil strength due to crusting and cementation on drying, consequently affecting the θ_{DTL}. There are few studies that have investigated the effect of SOC on the water contents for tillage. Although Dexter and Bird (2001) investigated the water contents for tillage for a silt loam in Highfield using the water retention approach, and Munkholm et al. (2002) a sandy loam soil in Askov using the consistency approach, they did not evaluate this effect statistically. There remains a need for more quantitative information on the SOC/water content relationship and its influence on tillage (Obour et al., 2017). Such information will help improve knowledge on how the physical condition of soil for tillage changes with changing SOC. In the present study, we investigated the effect of SOC on the water contents for tillage using both the water retention and consistency approaches to expand the findings of the previous studies. Our study focuses on water contents for secondary tillage used for seedbed preparation. It relates to unconfined fragmentation of soil aggregates rather than shearing of bulk soil.

The objectives of this study were to: (i) quantify the effect of SOC on the mechanical behavior of soil aggregates and the water contents for tillage, and (ii) evaluate the water retention and consistency approaches for determining the range of water contents for tillage. We hypothesized that the range of water contents for tillage increases with increasing SOC content.

2. Materials and methods

2.1. The experiments

Soil samples were taken from two long-term field experiments; the Highfield long-term, ley/arable experiment at Rothamsted Research, UK (51°80′N, 00°36′W) and from the Askov long-term experiment on animal manure and mineral fertilizers at Askov Experimental Station, Denmark (55° 28′ N, 09°07′E). These soils had uniform textures, but a range of SOC.

The soil from Highfield is a silt loam classified as Chromic Luvisol according to the World Reference Base (WRB) soil classification system (Watts and Dexter, 1997). The experimental site was originally established with grass, but for ~56 years prior to sampling, each of the plots has an unbroken history under its present management. As a consequence, the soil has a wide SOC gradient in the topsoil along the Bare fallow (BF), Continuous arable rotation (A), Ley-arable (LA) and Grass (G) treatments in the order: G > LA = A > BF (Table 1). The G treatment has been known as Reseeded grass, but throughout this paper, it will be called ‘Grass (G)’ treatment. The A, LA and G treatments were included in a randomized block design with four field replicates, whereas the four BF replicates were not part of the original design and were located at one end of the experimental site.

The soil from the Askov experimental site is a sandy loam classified as an Aric Haplic Luvisol according to the WRB classification system (IUSS Working Group WRB, 2015). The experiment includes the following four nutrient treatments: Unfertilized plots (UNF), and plots that have received ½ mineral fertilizer (½NPK), 1 mineral fertilizer (1NPK), and 1½ animal manure (1½AM). The nutrient treatments represent ½, 1 and 1½ times the standard rate of a given crop for total nitrogen (N), phosphorus (P), and potassium (K) in AM or NPK fertilizer (Christensen et al., 2017). The experiment utilizes a randomized block design with three field replicates. The different levels of nutrients applied results in a SOC gradient among the treatments in the order: 1½AM > 1NPK = ½NPK > UNF plots (Table 1). Crop management has been a four-course rotation of winter wheat (*Triticum aestivum* L.), silage maize (*Zea mays* L.), spring barley (*Hordeum vulgare* L.), and a grass-clover mixture (*Trifolium hybridum* L., *Medicago sativa* L., *Lotus corniculatus* L., *Lolium perenne* L., *Festuca pratensis* Huds and *Phleum pratense* L.) used for cutting in the following year (Jensen et al., 2017).

Table 1 shows the basic characteristics of the studied soils. For a more detailed description of the experiment and treatments in Askov and in Highfield reference is made to Jensen et al. (2017) and Jensen et al. (2018), respectively. From here on the soils are referred to with the treatment labels explained above.

2.2. Sampling

At Askov, sampling took place in September 2014 following a winter wheat crop. At Highfield, sampling was done in March 2015. At both Askov and Highfield, soil cores (6.1 cm diameter, 3.4 cm high, 100 cm^3) were taken from 6 to 10 cm depth by inserting steel cylinders gently into the soil. Six soil cores were sampled per plot at both locations. In addition, soil blocks were sampled at 6–15 cm depth: Two soil blocks (4000 cm^3) per plot in Askov, and three blocks (2750 cm^3) per plot in Highfield. The soil cores were stored in a field moist condition in a 2 °C room until analysis. Portions of the soil blocks per plot were spread out on a table and carefully fragmented by hand along natural planes of weakness and left to dry in a ventilated room ~20 °C.

2.3. Basic chemical and physical analysis

Air-dry soil samples from each plot was crushed to < 2 mm and SOC was determined by dry combustion using Flash 2000 NC Soil Analyzer (Thermo Fisher Scientific, Waltham, MA, USA). Soil texture was determined on portions of the < 2 mm samples using a combined hydrometer/sieving method after removal of soil organic matter by hydrogen peroxide (Gee and Or, 2002).

2.4. Soil water retention

To obtain water retention curves, water content was measured from the six soil cores per plot from Askov at −10, −30, −100 and −300 hPa matric potentials; and at −10, −30, −100, −300 and −1000 hPa matric potentials for Highfield soil on tension tables, vacuum pots and pressure plates (Dane and Hopmans et al., 2002). Water content at −15,000 hPa matric potential was determined from air-dry < 2 mm samples using WP4-T Dewpoint Potentiometer (Scanlon et al., 2002). Following equilibrium at each water potential the soil cores were oven dried at 105 °C for 24 h. Soil bulk density of each soil core was calculated from the mass of the oven-dried soil divided by the total soil volume. Bulk density was corrected for stone weight and volume for Highfield soil samples because they contained a significant amount of stones. Porosity was estimated from bulk density and particle density, where particle density was measured on one plot from each treatment using the pycnometer method (Flint and Flint, 2002). For the remaining plots, the particle density was predicted from SOC by a linear regression model. The pore size distributions of the soils were estimated from the water retention measurements, assuming the approximate relation:

$$d = -3000/\Psi \tag{1}$$