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Readily dispersible clay and particle transport in five Swedish soils under long-term shallow tillage and mouldboard ploughing

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ABSTRACT

Soil disturbance by tillage and traffic often adversely affects aggregate stability, leading to colloid and particle mobilisation, which may result in crusting, low water infiltration rate and sediment transport. Hence, minimising soil tillage is an important step in conserving soil quality. This study investigated readily dispersible clay (RDC) and particle transport as affected by shallow tillage or mouldboard ploughing in five Swedish long-term reduced tillage experiments that had been underway for 15–31 years at the time of soil sampling. The soils of the experimental sites are Eutric and Dystric Cambisols. RDC of soil samples, collected in 0–10 cm and 12–17 cm depth, from mouldboard ploughed (MP) and shallow tillage (ST) plots was compared by measuring turbidity. Particle transport was also determined in undisturbed soil columns (20 cm in diameter and 20 cm high) from these treatments. RDC and particle transport were significantly lower for ST than for MP at three sites where clay content was above 30%. Particle transport in two soils (clay content above 40%) increased with irrigation events, indicating that preferential transport dominated in unsaturated soil columns, but matrix flow and, consequently, particle dispersion increased as the soil approached saturation. Despite more organic C accumulation in the upper 0–10 cm of ST than in the 12–17 cm soil layer, clay dispersion was lower in the latter. Particulate P (Total P − dissolved P) was well-correlated to turbidity, suggesting that analysis costs often can be cut by only measuring turbidity. Shallow tillage generally produced positive environmental effects without negative effects on crop yield, especially on soils with high clay content.

1. Introduction

In a conventional tillage system, the main regulators of soil structure are tillage and traffic, while natural physical aggregate formation and biological processes play only a secondary role (Koistra and Tovey, 1994; Håkansson, 2005). Soil disturbance by tillage and traffic often damages soil structure, which may result in crusting, low water infiltration rate and erosion. To minimise these negative impacts and reduce energy consumption, various reduced tillage systems that are regarded as sustainable have been implemented in many countries. The importance of reduced tillage in minimising tillage costs and in erosion control has been well investigated and documented (Carter, 1994; Sijtsma et al., 1998; Tebrügge and Düring, 1999; Arvidsson et al., 2004). Until recently less attention was paid to particle and colloid losses from arable land with undulating topography; however, even moderate sediment losses from arable land through drainage or overland run-off will have negative consequences on a century time-scale. Both particulate-bound phosphorus (PP) and dissolved phosphorus (DRP) transport from arable land to Swedish lakes and streams may cause eutrophication. The rate of P fertilisation in Sweden today is basically compensation for P uptake by plants. In 1997, 20 and 30 kg ha^{-1} P were applied from mineral and manure fertilisers, respectively, but the corresponding figures were lower (15 and 27 kg ha^{-1}) in 2007 (WWW.SCB.se). However, there is about 2000 kg ha^{-1} bound P in the plough layer due to surplus fertilisation over 40–50 years. The dominant mode of P transport from fine textured soils is as particulate P (Sharpley et al., 1995; Uusitalo et al., 2001, 2003), which may have high bioavailability (desorbable particulate P). Thus, minimising the degree of soil disturbance is highly important for soil and water protection.

A number of Swedish long-term experiments with a variety of reduced tillage trials have been underway since the 1980s. The objective of the present study was to investigate readily dispersible clay (RDC) and particle transport as affected by shallow tillage or mouldboard ploughing, using five of these experiments. RDC is the amount of clay dispersed in water with insignificant energy input

Abbreviations: MP, mouldboard ploughing; ST, shallow tillage; MP-res, mouldboard ploughing, straw removed; ST-res, shallow tillage, straw removed; RDC, readily dispersible clay; WDC, water-dispersible clay.

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Table 1
Soil type, textural composition, soil organic matter content (g kg^{-1}) and total P (μm 100 g^{-1}) in the topsoil (0–25 cm).

Site and position	Soil type (WRB)	<2 μm	2–20 μm	20–200 μm	0.2–2 mm	P	Soil organic C		
							MP[a]	ST[b]	ST[c]
Ultuna (59°48′N/17°39′E)	Eutric Cambisol	506	284	189	21	64	19	26	19
Lönnstorp (55°40′N/13°E)	Dystric Cambisol	146	135	333	386	52	18	21	18
Röbäcksdalen (63°48′N/20°13′E)	Dystric Cambisol	84	295	589	32	49	24	31	27
Lanna (58°21′N/13°08′E)	Eutric Cambisol	429	357	153	61	61	17	22	18
Säby (59°49′N/17°42′E)	Eutric Cambisol	347	284	358	11	58	27	29	24

[a] 0–20 cm.
[b] 0–10 cm.
[c] 12–17 cm.

(Watts et al., 1996) and is an useful indicator of soil vulnerability with respect to particle mobilisation. Crop yields in the five long-term tillage experiments have been recorded annually and are summarised in Arvidsson (2007) and Arvidsson (2009).

2. Materials and methods

2.1. Experimental sites and soil sampling

The five experimental sites, representing major Swedish soil types, are described in Table 1. Soil sampling and laboratory investigations took place in 2004–2006. At four of the sites (Ultuna, Lönnstorp, Lanna and Röbäcksdalen), the trials had been underway for 30–31 years at the time of soil sampling for this study; soil sampling at Säby was carried out after 15 years of field trials. The experimental design for each site is given in Table 2. All trials were designed in a randomised complete block model (Montgomery, 1984) with four replicates (except the trial at Lönnstorp which had only three replicates). Soil samples were collected from the mouldboard ploughing (MP) and shallow tillage (ST) treatments, which are present on all five sites. In the MP treatment, annual ploughing to 22–24 cm depth is conducted in autumn. Ploughing in the trial at Lönnstorp is carried out in autumn or spring depending on the crop to be grown. At four sites, shallow tillage (ST) is performed using disc implements or field cultivators to 10–12 cm soil depth. ST at Säby was performed by Chisel plough. In the experiment at Lanna, additional soil samples were taken in sub-treatments with plant residue management (i.e., with straw chopped and incorporated or removed from the plot).

Soil samples were collected after harvest but before any tillage treatment in autumn, when the soil water content was nearly at field capacity, sampling in the wheel tracks from the latest harvest was avoided. Undisturbed soil columns and loose samples were collected in all replicates of MP and ST plots. The soil columns (20 cm in diameter and 20 cm high) were extracted by pushing mini-lysimeters into the soil using a soil anchor and hydraulic pump system. Loose soil samples were carefully excavated randomly from six points per plot, mixed and placed in a plastic box. Sampling was carried out in two layers of the topsoil (0–10 cm and 12–17 cm depth). Prior to laboratory tests, the samples were stored in a cold room at 2 °C in order to minimise biological activities and the risk of shrinking upon drying. The organic carbon content in the MP and ST treatments were determined in a portion of the loose samples by dry combustion using a LECO-2000 analyser (LECO Corp., St. Joseph, MI, USA).

2.2. Determination of water-dispersible and readily dispersible clay

Water-dispersible clay (WDC), readily dispersible clay (RDC) and clay concentration in drainage water were estimated by measuring turbidity, which has been found to be directly proportional to clay concentration in water (Watts et al., 1996; Czyz et al., 2002).

WDC was determined after mechanical disturbance of soil samples without the use of chemical agents (Brubaker, 1992). Air-dried and sieved (through 2 mm mesh) soil samples were used to determine WDC in MP and ST treatments for all replicates. In ST samples, WDC was determined for depths 0–10 and 12–17 cm (mean of two sub-samples per replicate). Tap water (250 mL) was added to 5.0 g soil samples in PVC bottles, which were mechanically shaken on a rotary shaker (90 rotations min^{-1}) for 12 h. The suspensions were then allowed to stand for settling of soil particles greater than clay size (>2 μm). A 30 mL sample of the suspension was then extracted by pipette from a depth of 50 mm (equivalent to a Stocks diameter of 2 μm or less) and its turbidity

Table 2
Design of the long-term tillage experiments at the five sites included in this study. Shallow tillage at all sites (except at Säby) was accomplished by disc harrow or field cultivators.

Site, start year	Treatment
Ultuna, 1974	A: Mouldboard ploughing to 22–24 cm (MP) B: Shallow tillage to 10–12 cm, occasionally as A C: Loosening to 22–24 cm with non-inverting implements, occasionally as A D: Shallow tillage to 10–12 cm (ST) E: Loosening to 22–24 cm with non-inverting implements
Lönnstorp, 1974	A: Mouldboard ploughing to 22–24 cm (MP) B: Ploughing for sugarbeet, other years as C C: Shallow tillage to 10–12 cm (ST)
Röbäcksdalen, 1976	A1: Mouldboard ploughing to 22–24 cm (MP), broadcasting of fertiliser A2: Mouldboard ploughing to 22–24 cm (MP) injection of fertiliser B1: Shallow tillage to 10–12 cm (ST), occasionally as A, broadcasting of fertiliser B2: Shallow tillage to 10–12 cm (ST), occasionally as A, injection of fertiliser C1: Shallow tillage to 10–12 cm (ST), broadcasting of fertiliser C2 Shallow tillage to 10–12 cm (ST), injection of fertiliser
Lanna, 1974	A1: Mouldboard ploughing to 22–24 cm (MP), residues removed A2: Mouldboard ploughing to 22–24 cm (MP), residues incorporated B1: Shallow tillage to 10–12 cm (ST), occasionally as A, residues removed B2: Shallow tillage to 10–12 cm (ST), occasionally as A, residues incorporated C1: Shallow tillage to 10–12 cm (ST), residues removed C2: Shallow tillage to 10–12 cm (ST) residues incorporated
Säby, 1991	A: Mouldboard ploughing to 22–24 cm (MP) B: Chisel ploughing to 10–12 cm (ST) C: Chisel ploughing to 15 cm D: Chisel ploughing to 20 cm E: Discing to 10–12 cm