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Tillage system effects on stability and sorptivity of soil aggregates

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A b s t r a c t. Stability and sorptivity of soil aggregates play an important role in numerous soil processes and functions. They are largely influenced by tillage methods. We have compared the effects of long-term application of various tillage systems on aggregate bulk density, rate of wetting, sorptivity, water stability, tensile strength and bulk density of silt loam Eutric Fluvisol. Tillage treatments were: 1) ploughing to the depth of 20 cm (CT), 2) ploughing to 20 cm every 6 years and harrowing to 5 cm in the remaining years (S/CT), 3) harrowing to 5 cm each year (S), 4) sowing to uncultivated soil (NT), all in a micro-plot experiment. Bulk density of soil aggregates was determined by wax method, sorptivity – by a steady state flow, water stability – by drop impact method, and tensile strength – by crushing test. Tillage had a significant effect on the aggregate characteristics. Soil aggregate bulk density and water stability were greater and rate of wetting and sorptivity were smaller in reduced and no-tillage treatments compared with CT. Greater soil organic matter and bulk density accompanied greater water stability. Smaller rate of wetting and sorptivity can be associated with lower aggregate porosity. The differences in the rate of wetting, sorptivity, and water stability of the initially air-dry soil aggregates and bulk density between the tillage treatments were relatively greater than those in the tensile strength.

K e y w o r d s: tillage, soil aggregates, stability, sorptivity

INTRODUCTION

Characteristics of soil aggregate stability are used to describe tillage effects on soil structure because they affect the maintenance of tilth (Karlen, 1990), the availability of water for plant roots (Horn, 1994) and evaporation (Witkowska-Walczak, 2000). Low water stability of soil aggregates and associated susceptibility to surface sealing due to rainfall impact are *eg* the main causes of low infiltration rate and consecutive sealing and hazard of soil erosion (Rejman *et al*., 1994; Igwe, 2000; Becher, 2001; Tebrügge and Düring, 1999; Franzluebbers, 2002). Arable soils are subjected to repeated wetting and drying throughout the year and, therefore, high aggregate stability is fundamental for the maintenance of proper tilth (Karlen, 1990; Becher, 2000). Stable soil aggregates provide a greater number of continuous and interconnected pores (Mc Garry *et al*., 2000; Wiermann and Horn, 2000) and have the potential to greatly influence infiltration and transport of surface-applied agricultural chemicals in soil and to surface water or the groundwater (Heathman *et al*., 1995). However, not only the properties of the bulk soil but also that of aggregate-pore characteristics constitute an important factor affecting soil water conductivity and storage (Witkowska-Walczak and Sławiński, 2005).

Strong aggregates provide stable traction for farm implements, diminish compactability of soil (Horn and Rostek, 2000), but limit root growth inside aggregates (Gliński and Lipiec, 1990) due to the presence of small and discontinuous pores influencing mechanical impedance, and/or to insufficient aeration status. As a consequence, the preferred root growth occurs between the aggregates which, however, restrict access to water and nutrients of which extent can be dependent on the tensile strength of aggregates affecting soil friability (Dexter and Watts, 2001; Munkholm and Kay, 2002).

Sorptivity of soil aggregates is an important characteristic with respect to water flow (Leeds-Harrison *et al*., 1994). It is useful in separation of the flow in the less mobile micropores of the aggregate and very conductive macropores.

Responses of the aggregate characteristics to tillage systems are significantly affected by bulk density (Horn, 1986; Becher, 2000) and organic matter content (Watts and Dexter, 1998) that are influenced by soil tillage methods

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(Lipiec *et al*., 2006). The aim of this study was to evaluate the effect of long term use of various tillage systems on aggregate stability and sorptivity of silt loam Eutric Fluvisol.

MATERIALS AND METHODS

The experiment was performed on Eutric Fluvisol according to the World Reference Base for Soil Resources (FAO, 1998) legend, at the experimental field of the Institute of Soil Science and Plant Cultivation in Puławy (51.25°N, 21.58°E), Poland. The soil contains 25% of clay (< 2 μm), 62% of silt (2-50 μm) and 13% of sand (50-2000 μm) at the depth of 0-30 cm.

The experimental design used randomised block with four replicates of micro-plots (1x1.5 m). The treatments were as follows: 1) ploughing to the depth of 20 cm (CT); 2) ploughing to 20 cm every 6 years and harrowing to 5 cm in the remaining years (S/CT); 3) harrowing to 5 cm each year (S); 4) sowing to uncultivated soil (NT). Hand implements were used to simulate all the tillage operations as much as possible. The use of such implements allowed to avoid soil compaction by traffic. The treatments were applied during 18 years (from 1979 to 1997) with crop rotation including maize, spring barley, winter rape, winter wheat and faba bean. Weeds were controlled with pre-emergence application of Roundup [glyphosate, η-(phosphonometyl)glycine] or Gramoxone (paraquat. 1.l'-dimethyl-4,4'-bipyridinum salts) (Kuś, 1991).

Soil samples were taken in 1997 just after harvesting spring barley. The samples from all treatments were air-dried under the same conditions at temperature of 18°C because the strength of bonds holding aggregates together changes substantially depending on time and intensity of drying (Bullock *et al*., 1988). Average soil water content of the aggregates was 3.7% w/w being lower than that at soil potential -1.5 MPa.

The rate of wetting and sorptivity (40 replicates) of initially air-dry aggregates were determined using the device described by Leeds-Harrison *et al*. (1994). The device was successfully used for aggregates of size greater than 20 mm. Therefore, we used similar size of aggregates (20-30 mm) in the form of natural clods. The device infiltrated water through a circular surface area of the sponge. During wetting, a steady state flow occurred in the horizontal capillary tube connected with the tip of the device where the soil aggregate was in contact with a circular area of the sponge. Sorptivity, S, was obtained from the modified Wooding formula (quoted by Leeds-Harrison *et al*. (1994):

$$S = \sqrt{\frac{Qf}{4bR}} \qquad (2)$$

where: Q – is the steady-state rate of flow through a circular tube of radius R = 1.45 mm; f – is the fillable porosity obtained with the modified standard wax method (the aggregates were weighed and next covered by water-resistant lacquer for determining the volume of single aggregate, necessary to calculate bulk density. The fillable porosity was then calculated using aggregate's bulk density and the specific density of the soil material); b - is the parameter that depends on the shape diffusivity function (usually assumed as 0.55).

To measure water stability of aggregates (20 replicates for CT and NT, 15 replicates for S/CT and S) taken from top horizons, we used the drop impact method described by Rząsa and Owczarzak (1983). The measurements were done on initially air-dry natural soil aggregates of 9-10 mm. Water drops weighing 0.05 g were falling down from the height of 1 m and hit the aggregate with the energy of 4.905 10^{-4} J. The number of falling drops that caused the initial, half and then total breakdown of the soil aggregates was counted to give the measure of the aggregate stability. The use of the method allows the simulation of impact forces occurring during rainfall (Reichert and Norton, 1994).

The crushing strength of a single natural air-dry aggregate of a 9-10 mm diameter (50 replicates) was determined using a strength-testing device (Pawłowski *et al*., 1996). The diameter of an individual aggregate was estimated as the mean of different measurements taken along three axis of the aggregate: the longest, intermediate, and the shortest, as suggested by Dexter and Kroesbergen (1985). An aggregate was put in its most stable position on a metal plate and crushed with another plate attached to the fixed tensometric head. The value of tensile strength, q, was then calculated from the equation:

$$q = 0.576\, F/d^2 \qquad (1)$$

where: F – is the polar force at failure (N), d – is the mean diameter of the aggregate (m).

RESULTS

Rate of wetting and sorptivity

There was an effect of tillage on the rate of wetting (volume of water entering the aggregates as a function of time), with the CT system having the greatest wetting rate and the S/CT tillage system having the least wetting rate throughout the time of measurement (Fig. 1). The volume of water entering CT aggregates at the end of wetting was 403 mm^3 and decreased by 60, 46.7, and 26.8 % in S/CT, S, and NT, respectively. The data in Table 1 indicate that aggregate sorptivity, similarly as the rate of wetting, was substantially greater in CT (0.109 mm $s^{-1/2}$) than in the remaining treatments (0.029-0.044 mm $s^{-1/2}$). The greater rate of wetting of CT aggregates can be associated with larger aggregate porosity, being 0.449 m^3 m^{-3}, compared to that in other treatments (0.357-0.426 m^3 m^{-3}). In the treatments with reduced tillage and no-tillage, the rate of wetting can be

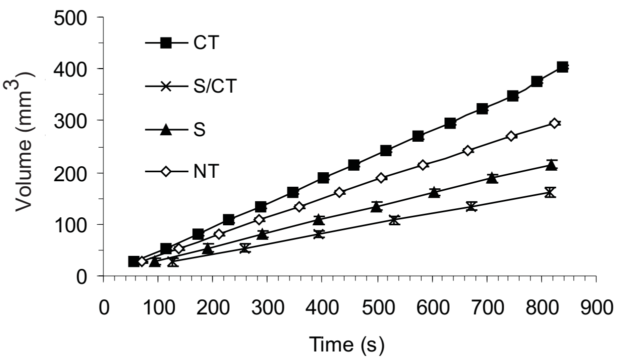

Fig. 1. Rate of wetting of soil aggregates for four tillage treatments. Each point represents the average of 40 replicates. Bars represent standard error.

additionally reduced by greater soil organic matter content (Table 1). However, we have to consider that the pores or the bulk aggregate would additionally alter the infiltration due to hydrophobicity caused by pre-drying (Horn *et al*., 1994; Rasiah and Kay, 1995).

Water stability

Figure 2 shows that water stability was the lowest in CT at all disintegration stages. On average the total breakdown of the CT aggregates was caused by 218 drops and increased in S/CT, S and NT by 29, 68.3, and 67.9% , respectively. The lowest water stability under CT compared to all treatments with less tillage intensity can be associated with loose particle-to-particle associations (Kemper *et al*., 1987) as shown by smaller aggregate bulk density and associated greater porosity (Table 1). Other studies (Kay and Angers, 1999; Mamedov and Levy, 2001) showed that these characteristics can diminish aggregate stability by aggregate breakdown and slaking during wetting, caused by air entrapped in the aggregates. A greater aggregate stability in the S/CT, S and NT than CT treatments can be additionally enhanced by higher organic matter content (Table 1). Enhancing effect of organic matter concentration on aggregate stability under conservation tillage systems has been reported in earlier studies (Chan *et al*., 1994; Arshad *et al*., 1999; Hernanz *et al*., 2002). Higher contents of stable aggregates significantly contribute to greater inter-aggregate porosity at the surface of the soil and infiltration, preventing the onset of runoff (Mamedov and Levy, 2001; Rhoton *et al*., 2002). Comparison of Figs 1 and 2 and Table 1 reveals that the greatest wetting rate under CT was accompanied by the lowest water stability of soil aggregates, which can be due to greater slaking at wetting. Turski *et al*. (2000) have reported similar results with respect to aggregates from various soil horizons. The results agree with the findings reported by Rasiah and Kay (1998) indicating that the rate of wetting provides an indication of the extent of soil destabilization.

Tensile strength

This study showed that tillage had no clear effect on soil aggregate tensile strength (Fig. 3). The limited effects of the tillage could be due to the combined effect of bulk density that can enhance (Horn, 1986; Benjamin and Cruse, 1987) and $C_{org.}$ that can decrease mechanical stability of aggregates. Thus, finally, tensile strength decreases (Hadas, 1987; Watts and Dexter, 1998). In our study, these effects are reflected in similar aggregate tensile strength values under CT and NT, with the lowest and the highest values of both bulk density and $C_{org.}$, respectively. Moreover, this similarity could be due to the use of light hand tillage implements in our experiment that did not strongly compact the soil. However, in a soil more compacted by traffic and tillage with heavier machinery, combined with soil displacement due to shearing and shrinking and swelling, the compaction can result in denser soil with a greater number of contact points or higher forces at each single contact point and, consequently, greater internal aggregate strength (Horn, 1990; 2004).

T a b l e 1. Some characteristics of the aggregates

Properties	CT*	S/CT	S	NT
$C_{org.}$ (% w/w)	2.16	2.20	2.43	2.51
Bulk density (Mg m^{-3})	1.460 (0.023)**	1.543 (0.027)	1.521 (0.022)	1.705 (0.024)
Porosity ($m^3 m^{-3}$)	0.449 (0.0086)	0.418 (0.010)	0.426 (0.083)	0.357 (0.0089)
Sorptivity (mm $s^{-1/2}$)	0.109 (0.012)	0.029 (0.0025)	0.041 (0.0027)	0.044 (0.0028)

*CT – conventional tillage (ploughing to 20 cm); S/CT – conventional tillage every 6 years and harrowing (5 cm) in other years; S – harrowing (5 cm); NT – not tilled. ** Standard errors are given in brackets.

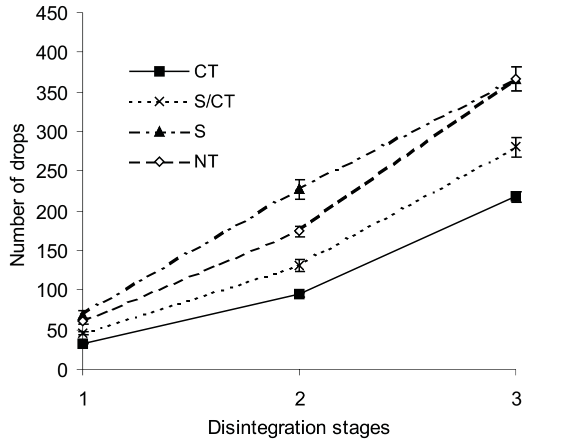

Fig. 2. Water stability of soil aggregates for four tillage treatments. Each point represents the average of 15-20 replicates. Bars represent standard error.

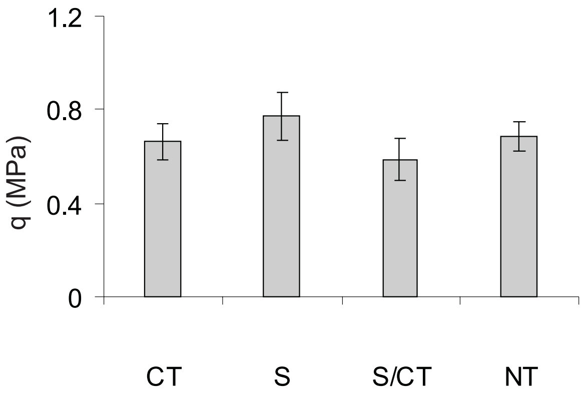

Fig. 3. Tensile strength, q, of soil aggregates for four tillage treatments. Average of 50 replicates. Bars represent standard error.

CONCLUSIONS

1. Long term application of various tillage methods (conventional tillage, reduced tillage and no-tillage) on silt loam Eutric Fluvisol resulted in different air-dry aggregate characteristics.

2. Reduced and no-tillage, compared to conventionally tilled treatments, increased aggregate bulk density, organic matter content, water stability, and reduced rate of wetting and sorptivity.

3. The effect of tillage methods on tensile strength of soil aggregates was much less pronounced than on other aggregate characteristics.

4. Greater aggregate water stability was accompanied by smaller porosity and rate of wetting.

5. The differences in the aggregate structure may largely influence soil susceptibility to degradation.

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