

Water-Stable Aggregation in Relation to the Normalized Stability Index

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Abstract: In spite of the good quality of soils in Hungary, soil structure is deteriorated by intensive tillage. Because of general dissimilarities between field and laboratory circumstances and therefore lack of comparability, the former results are questionable. An optimized method initiated by Six, Elliott, and Paustian (2000) was adapted to investigate changes in soil structure and quality caused by different kinds of added organic matters. Our samples originated from the long-term fertilization experiments in Keszthely, western Hungary. The experiments were set up in 1960. The texture of the investigated soil is sandy loam; the type of soil is Eutric Cambisol (soil type FAO) or Alfisol (soil type USDA). Tillage and its depth was fall plowing to 25 cm. Crop rotation was maize–maize–potato–winter wheat–winter wheat. Samples were taken from depths of 0–20 and 20–30 cm, from the fallow, which had the same treatment as the potato field. Changes in soil structure were quantified by wet sieving. Soil structural stability was characterized by comparing aggregate size distribution after the use of a lower and a higher disruptive force, which was simulated by two different pretreatments. Determinations were done in triplicates. Soil structure may be improved by adding readily decomposable organic matter. The extent of amelioration depends on the chemical buildup and decomposability of the crop residues. Three different kinds of organic matters were investigated: (1) maize stem (M), (2) wheat straw (W), and (3) maize stem and wheat straw (MW). By comparing the aggregate stabilizing effects of the differently decomposable organic matters to each other and predicting the lower decomposability but persisting effect of M, the expected $MW > M > W$ order was proven. These are parallel with those results of Harris, Chesters, and Allen (1966) and John et al.

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(2005), who observed decreasing aggregate stability in the $M > W$ order. We observed increased macroaggregate stability in both macroaggregate fractions (2000–7000 μm and 250–2000 μm) in all three case of organic-matter addition, but these newly formed bindings were easily broken up because of the weaker bindings of the higher aggregate hierarchical orders. This is remarkable mainly in the upper layer because crop residues were mixed to the upper layer and therefore could not have affected the lower one. Furthermore, adding organic materials has decreased the mass of the 53–250 μm microaggregate fraction in all treatments and depth layers and in addition in both pretreatments. This proves that adding organic matter enhances the transient and temporary binding agents between microaggregates grouped into macroaggregates but that these bindings are temporal.

Keywords: Aggregate stability, maize and wheat residues, soil structure, tillage

INTRODUCTION

In the past hundred years, with the explosive growth of the human population, natural resources have been more utilized to supply food. Among these natural resources, soil is primary because it supplies the basic media for crop management and therefore allows the production of food by agriculture (Várallyay 2002). Nevertheless, more intensive tillage and crop management may cause irreversible harmful effects to it, endangering the sustainability of its quality and therefore agricultural productivity.

Tillage and crop management may cause decline of soil structure and degradation of its stability because of the loss of organic matter, destruction of structural elements, and too rapid wetting (Chan and Heenan 1999). Soil structure and its stability are affected by the concentration of organic matter to a high extent. Ameliorating and stabilizing soil structure by adding organic matter like farmyard manure, crop residues, or green manure are general practices, but their effect on soil structure depends on several factors such as quantity and quality (i.e., decomposability). Organic matter may enhance soil structural stability when it decomposes in the soil. Therefore, incorporation of decomposable fresh crop residues and green manures may amend soil structure, in contrast to farmyard manure, because manure has highly decomposed during its fermentation. Because of the continuously decreasing number of cattle, increasing manure prices, and removal and burning of crop residues, adding different kinds of organic matter is becoming rare. In the area of the field experiment, these unfavorable management practices are general and may cause a decrease of organic matter in the soil and therefore degradation. Consequently, our study intends to amend soil structure with the addition of various organic matters to the soil.

Structure of soil and its quality are important for crop management because they allow and mediate many biological and chemical processes

in soils. Therefore, efficient protection of soil structure is crucial, which needs clear and comparable detection of changes in it. Detecting the changes in soil structure caused by tillage gives us the possibility to sort out those kinds of tillage practices that do not danger the soil structure and moreover prevent soil degradation or ameliorate the former injuries.

Since the early 20th century, differences and changes in soil structure in different crop management systems have been investigated in many countries. Nevertheless, because of dissimilarities between the different investigations and field and laboratory circumstances, and therefore lack of comparability, the former results are questionable (Six, Elliott, and Paustian 2000).

In this article, our aim was to test a new standardized wet-sieving method to determine whether it is able to detect the differences in soil structure caused by different tillage systems. We investigated the effect of addition of three different kinds of organic matter, namely maize stem (M), wheat straw (W), and the mix of these two matters (MW), on soil structure and on the stability of aggregates.

Investigating the Stability of Soil Aggregates

Soil structure is built up by groups of primary particles that cohere to each other, which are called aggregates (Kemper and Rosneau 1986). Soil structure is optimal for crop management in the case when the whole soil mass is built up by single aggregates that are bigger than 250–500 μm (Di Gléria, Klimes-Szmik, and Dvoracek 1957). Wetting of aggregates could be severely disruptive, because during rapid wetting the air escaping from the pores of the aggregate generates high pressure, which blows up the aggregate. So, aggregates are decomposed into fragments of aggregates and primary particles (Emerson 1977). Therefore, quality and stability of soil structure depend on the stability of aggregates in water. This property is often investigated by wet sieving. Nevertheless, because of dissimilarities and other methodological problems, results of the research made in this field in the past hundred years are questionable.

A new standardized wet-sieving method proposed by Six, Elliott, and Paustian (2000) was investigated. Weight of water-stable soil aggregate fractions resulted by this wet-sieving method were used to calculate the Normalized Stability Index (NSI). NSI makes the differences or changes in soil structural stability between the different soil types, tillage practices or erosion numerically comparable. The values of NSI may differ between 0 and 1, it is a unitless value. Higher NSI values show higher aggregate stability therefore better soil structure. Lower NSI values show lower aggregate stability, the higher sensitivity of soil to the disrupting effect of too rapid wetting (by too intense irrigation or rainfall.) The wet-sieving

method, used to calculate the Normalized Stability Index (NSI), excludes the confounding effects and standardizes the method for assessing water stability of aggregates. To make the results comparable, (1) the different-sized structural units of different soil types have to be broken into a given size range, (2) the differently moist field samples have to be air dried, and (3) the air-dried samples have to be moistened to a given moisture contents. To make the different mineral particle distribution of different sites comparable, (4) the mineral fraction is excluded. The NSI characterizes aggregate stability by comparing the aggregate distribution after two different prewetting methods and a standardized disruptive force. The same sieving time and the same sieving frequency ensure the standardized disruptive force. The two different wetting methods are (1) fast wetting, namely rapid immersion in water [slaking (S)], which disrupts the aggregates to the highest extent, therefore producing the lowest aggregate mass, and (2) slow wetting, namely capillary wetting [capillary (C)] to field capacity, which disrupts the aggregates to the lowest extent and therefore achieves the highest aggregate mass. The capillary wetting method was tried by us earlier to get different size fractions to evaluate the distribution of soil organic matter in soils (Huisz et al. 2006).

Effect of Crop Residues on the Stability of Aggregates

The return of organic matter (farmyard manure or different kinds of crop residues or organic manure) to improve soil quality and stability has a historical tradition. The incorporation of crop residues to soils may raise the level of soil organic matter and increase aggregate stability (Lynch and Elliott 1983).

Different kinds of added organic matter cause different levels of aggregate stability: it is correlated with the combined effects of mass, particle size, and biochemical composition of the crop residues returned to soils (Martens 2000) and affected by the soil type (Paul 1984).

With decreasing particle size, the surface of crop residues attacked by microorganisms increases; therefore, they get more decomposable. Breaking crop residues before mixing it with soil therefore enhances its accessibility to microorganisms and increases decomposability, which in turn increases aggregate stability.

The water stability of aggregates depends on the decomposability of plant residues, which is influenced by the biochemical composition of them (Martens and Frankenberger 1992; Martens 2000). Crop residues contain the same classes of organic compounds: proteins, saccharides, humic acids, phenol acids, and lignin, but the proportion of them is affected by the plant species and the stage of maturity, which may influence the degree and rate of decomposition and therefore the effect on

aggregate stability. The more decomposable organic compounds (glucose) have rapid but transient aggregate binding effects (up to several weeks), contrary to the slower decomposing organic materials (cellulose), which have fewer effects but persist for months (Tisdall and Oades 1982). Piccolo, Pietramellara, and Mbagwu (1997) mentioned a humus compounds > phenolic compounds > lignin > cellulose and peptides order of organic compounds, which marks decreasing resistance and shorter-term effects on aggregate stabilization.

Plant-derived carbohydrates have bigger particle size, occur in the sand fraction, and are easily decomposable (Schulten and Leinweber 2000). Decomposed by microorganisms, they enhance soil aggregation in a rapid but transient way. Polysaccharides are readily mineralizable and act as short-affected transient binding agents initiating aggregation (Kay 1998; Tisdall and Oades 1982). These substances may adsorb strongly onto mineral surfaces (Kay 1998; Martens 2000) and form gel-like compounds, binding soil particles together (Haynes and Beare 1997). Phenols and polyphenols may form cationic bridges and therefore increase aggregation (Martens 2000). The higher the lignin concentration in the crop residue is, the lower the decomposition is (Palm and Rowland 1997). Lipids may improve water stability of soil aggregates, probably related to their hydrophobic nature (Dinel et al. 1997; Pare et al. 1999). Humic substances may increase aggregate stability as a result of their chemical resistance and association with soil particles (Piccolo, Pietramellara, and Mbagwu 1997).

With adding decomposable organic matter to soils, all compounds mentioned previously give their effects on water stability of aggregates (Tisdall and Oades 1982).

Several investigations were made to assess the effect of different kinds of added and chemically different organic matter on soil structure and water stability. According to Raimbault and Vyn (1991), mixing maize residues increases aggregation because of high concentration of the involved phenols. Martens (2000) reported rapid, transient increase in water stability of aggregates in the case of adding low phenolic-acid-containing alfalfa, canola, and clover residues and more pronounced increase in water stability of aggregates in the case of adding higher phenolic-acid-containing maize, prairie grass, oat, and soybean.

John et al. (2005) investigated the effects of wheat and maize crop residue incorporation on the water stability of aggregates. The aggregate stability decreased in the maize > wheat order in the upper layer, but these changes were not significant and were less pronounced in the lower layer.

Soil type influences the extent of soil aggregation through the presence and rate of clay minerals, which protect microbial metabolites originating from the decomposition of crop residues and therefore enhance the stability (Paul 1984).

The stability of macroaggregates highly depends on the presence of living roots and decreases with the decomposition of them (Oades and Waters 1991). Therefore, adding easily decomposable organic matter may increase the stability of macroaggregates. In contrast with this, the stability of microaggregates is almost independent of the presence of easily decomposable organic matter (Tisdall and Oades 1982; Christopher et al. 1996). Microaggregates are stabilized mainly by inorganic components, not by organic matter (Monreal et al. 1995).

MATERIALS AND METHODS

Site Description

The soil samples originate from the “Comparing experiment of organic and mineral fertilization” long-term field experiment (crop rotation B) in Keszthely, Hungary. The investigated soil type is a sandy loam Eutric Cambisol (soil type FAO), Alfisol (soil type USDA). The soil of the experimental field is poor in available phosphorus (P), moderate in potassium (K), and low in organic matter (OM; 1.7%) and has the following characteristics: soil pH_{KCl} 5.9; content of calcium carbonate (CaCO_3) 0.1%; and the percentage of clay (<0.002-mm fraction) 24%. In this article, addition of three different kinds of organic compounds have been investigated: (1) maize stem (M), (2) wheat straw (W), and (3) maize stem and wheat straw (MW) were mixed and compared to an inorganic manure added as a reference. In all four treatments, 146 kg of nitrogen (N), 80 kg of P, and 100 kg of K mineral fertilizers were added (per ha). All sites have been tilled by autumn plowing to 25 cm deep. Crop residue mixing was done simultaneously with the autumn plowing every year since the setup of the experiment. Soil samples were taken from two different depth layers: the first from the depth of tillage (upper layer: 0–20 cm) and a 10-cm-thick second layer under the depth of tillage (lower layer: 20–30 cm). The experiment was set up in 1960. Crop rotation was maize–maize–potato–winter wheat–winter wheat. Samples were taken from a fallow, which has had the same treatment as the potato field, because our aim was to investigate the organic-matter addition but to exclude to the soil degrading effect of hilling planting of potato.

Soil samples were taken with a spade and were delivered in plastic boxes to avoid pressing of the natural structure. Field-moist soil samples were manually gently broken apart into pieces smaller than 3–5 cm in diameter to avoid drying them into clods. Air-dry soil was dry sieved in a 7-mm sieve; parts bigger than this size were manually broken with a mortar to reach this size. Two different pretreatments were investigated (Figure 1). Air-dried soil, ± 300 g, was rapidly immersed in tap water for 5 min [slaking (S)]. Also, ± 300 g-s of air-dry soil was capillary wetted through a

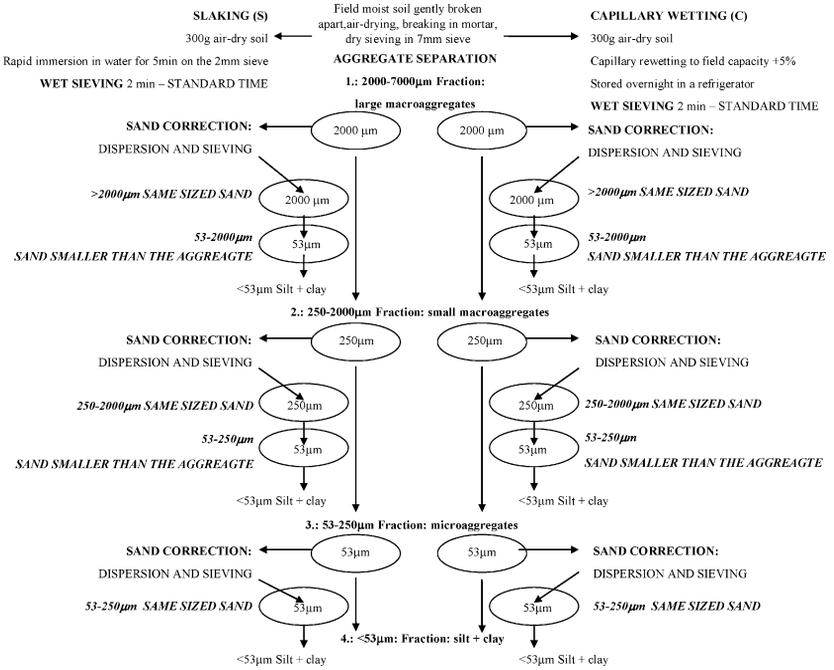


Figure 1. Schema of the aggregate separation and sand correction.

nylon filter to field capacity and left overnight to weight equilibrate [capillary (C)]. After the pretreatment, each sample was wet sieved for 2 min in an analytic sieve shaker at the frequency of 70 strokes per min with the following aperture sizes: 2 mm, 250 µm, and 53 µm. Wet sieving was done manually by some authors (Six, Elliott and Paustian 1999, 2000; Márquez et al. 2004; Cambardella and Elliott 1993). Therefore, different fractions are sieved separately: the mass of sample rested on the mesh of a sieve is washed onto the next smaller aperture sieve and then sieved again. Therefore the (1) fraction was sieved for 2 min, the (2) fraction was sieved for 2 + 2 min, and the (3) and (4) fractions were sieved for 2 + 2 + 2 min. Therefore, the smaller the fraction size is, the longer the sieving time and hence the disrupting force. These are opposite to the conditions when we determined the NS because it needed a standardized sieving time and a standardized disrupting force. Another problem with doing the wet sieving manually was that it was not replicable. We believe their results were questionable. Therefore, we used an analytic sieving machine to use the same disrupting force and the same sieving time. In this way, our results were comparable and reliable. The mass of samples resting on the mesh of the sieves were rinsed gently to avoid leaving silt and clay particles among the aggregates. Therefore, we got four fractions: (1) the 2000–7000 µm large macro-, (2) the 250–2000 µm small macro-, and (3) the 53–250 µm

microaggregates, as well as (4) the $<53\ \mu\text{m}$ silt and clay fraction. Fractions 1–3 were gently backwashed into preweighed aluminium pans. The supernatant was taken out after settling. Fraction 4, flowing out from the sieve shaker machine, was collected in a bucket, left to settle for some days, and washed into a preweighed aluminium pan after the removing of the supernatant. All fractions were dried on hot plates at $60\ ^\circ\text{C}$ and left overnight in a drying machine at $60\ ^\circ\text{C}$ to be weight equilibrated. Sand size distribution for fractions 1–3 was determined by dispersing the aggregate fractions with sodium hexametaphosphate ($5\ \text{g L}^{-1}$ for 18 h). Mineral fractions were backwashed into preweighed aluminium pans and dried at $105\ ^\circ\text{C}$ to weight equilibration. To avoid overestimating the mass of the aggregate fractions, aggregate-sized sand fraction was subtracted from the whole fraction masses (this method is called “sand correction”).

RESULTS AND DISCUSSION

Soil samples were taken from four plots of each treatment and from two depth layers. Different pretreatment methods were done in triplicates. There were altogether 4×3 statistical replicates. In this article we present our results before the sand correction. Results of experiments were accepted when their variances were less than 5% compared to the other two members of the triplicate, otherwise the wet sieving was disregarded and a new replicate was done. Data were analyzed with SPSS ANOVA (SPSS, Chicago, IL). Statistical significance was determined at $P < 0.05$.

Figure 2 shows weight of soil mass in the isolated fractions for each treatment and depth layer. Table 1 shows the changes in dry mass of fractions for the effect of the investigated treatments (in the percentage of the Control treatment).

Three different kinds of organic matter and their effects on the water stability of aggregate size fractions were investigated by a new proposed wet-sieving method on a sandy loam soil.

First, the different dry mass of the aggregate fractions caused by the two different pretreatments was remarkable. The first and more disruptive pretreatment (S) caused the whole disintegration of the less resistant 2000–7000 μm large macroaggregate fraction in all treatments and depths, but the C pretreatment did not (Figure 2). With its stepwise disintegration (Oades and Waters 1991), this fraction dispersed into mainly 53–250 μm microaggregation fraction and $<53\ \mu\text{m}$ silt and clay fraction in the S pretreatment in both depths. Mass of these fractions was much more than with C pretreatment. These results parallel with those of John et al. (2005), who investigated the effect of maize and wheat crop residues on the water stability of aggregates with the same S pretreatment. In their experiment, the highest mass of water-stable aggregates was in the 53–250 μm

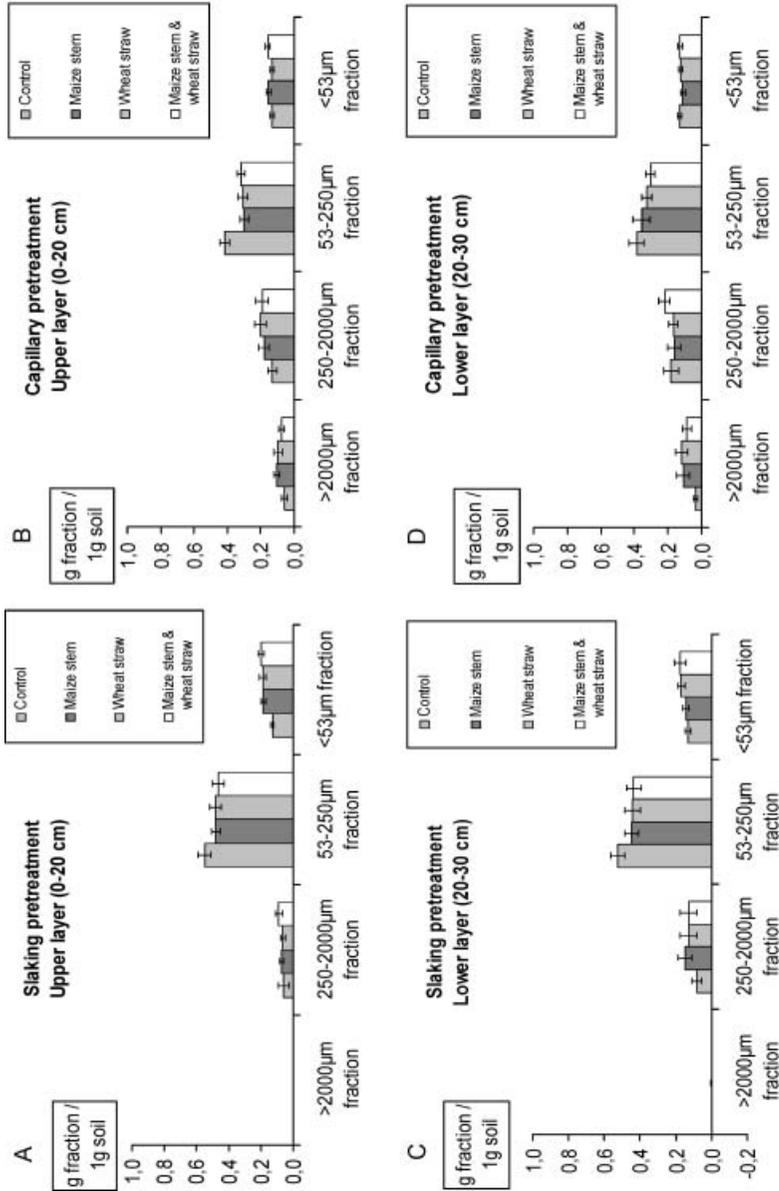


Figure 2. Size fractions (g fraction 1 g^{-1} soil), and the standard deviation at $P > 0.05$) obtained by the different pretreatment methods of the investigated treatments in the upper (0–20 cm) and the lower (20–30 cm) depth layers.

Table 1. Changes in dry mass of fractions as the result of the investigated treatments (in percentage of the Control treatment)

Treatment	Pretreatment	Layer	Fraction				
			2000–7000 μm	250–2000 μm	53–250 μm	<53 μm	
Maize stem mixing	Slaking (S)	Upper (0–20 cm)	No fraction	24.92	-12.37*	43.93*	
		Lower (20–30 cm)	No fraction	83.11*	-15.06*	8.92	
	Capillary (C)	Upper (0–20 cm)	85.13	38.12*	-28.13*	15.34*	
		Lower (20–30 cm)	188.20*	-11.12	-7.70	-15.90	
Wheat straw mixing	Slaking (S)	Upper (0–20 cm)	No fraction	10.92	-12.13*	46.31*	
		Lower (20–30 cm)	No fraction	59.99	-15.40*	27.81*	
	Capillary (C)	Upper (0–20 cm)	71.72*	53.81*	-25.91*	-0.71	
		Lower (20–30 cm)	215.14*	-7.86	-15.86*	-3.90	
Maize stem and wheat straw mixing	Slaking (S)	Upper (0–20 cm)	No fraction	47.81	-15.32*	51.96*	
		Lower (20–30 cm)	No fraction	60.04	-16.98*	33.07*	
	Capillary (C)	Upper (0–20 cm)	28.87	47.05*	-23.67*	18.13*	
		Lower (20–30 cm)	130.51*	22.22	-21.39*	-1.17	

Notes. Asterisk (*) indicates significant effect on the water stability of aggregates caused by the organic-matter addition compared to the mean of the control in respective depth within a soil fraction shown by ANOVA at $P > 0.05$. Number of replicates was 12.

microaggregate fraction for maize residues and the 250–1000 μm smaller macroaggregate fraction for wheat, but differences between wheat and maize residues were not significant. In our experiment, mass of the 250–2000 μm small macroaggregate fraction was less remarkable in this pretreatment than in the less disrupting C pretreatment.

In the less disruptive C pretreatment, higher mass of this 2000–7000 μm large macroaggregate fraction is detectable (in all treatments and layers). These results are parallel with those of Christensen (1986), who investigated the effect of barley straw incorporation on mass of aggregates by dry sieving. He reported increasing in mass of large (1–20 mm) macroaggregates in a loamy sand soil. Yadvinder et al. (2000) presented results of the same tendency. They investigated wheat straw incorporation plus N fertilizer application with the wet-sieving method and observed the increased mass of >2 mm large macroaggregates. In our experiment, the dominating role of the 53–250 μm microaggregate fraction has not changed, but because of the less disrupting forces, higher mass of the 250–2000 μm small macroaggregate fraction was resulted. Therefore, mass of the <53 μm silt and clay fraction is decreased. Our results parallel those of Christensen (1986), who observed a decrease in silt and clay mass by the increasing mass of the bigger sized (250–2000 μm) aggregate fractions as the result of barley straw incorporation by dry sieving of a loamy sand soil.

Martens (2000) reported lower decomposability but persisting aggregate stabilizing effect of maize (M); therefore we expected the $M > W$ order in stabilizing aggregates. By comparing the effects of the different kinds of organic matters, the clear trend of increased macroaggregate stability is visible in all the two macroaggregate fractions. This is remarkable mainly in the upper layer, less in the lower layer, in the case of the C pretreatment. Mass of the 2000–7000 μm large macroaggregate fraction has decreased in the $MW > M > W$ order. These changes are not detectable in the case of S pretreatment as a result of the more extended disruptive force. Furthermore, adding organic materials has differently decreased the mass of the 53–250 μm microaggregate fraction in all treatments and depth layers in both pretreatments.

Parallel changes in the dry mass of fractions of different depth layers caused by the different organic matters are detectable in the S pretreatment but not in the case of C pretreatment. In the S pretreatment, all three kinds of organic matter have increased mass of the 250–2000 μm large macroaggregate fraction (in different order in the lower and upper layer), decreased mass of 53–250 μm microaggregate fraction in the order of $M \approx W > M$ and W and have increased mass of the <53 μm silt and clay fraction in the $M > W > MW$ order (parallel in the lower and upper layer).

These results are contrary to those of Bordovsky, Choudhary, and Gerard (1999), who described higher microaggregate mass with wheat residue retaining rather than residue removing.

Parallel changes in the mass of fractions of different pretreatments in the upper layer caused by the different organic matters are questionable because of the small differences. John et al. (2005) described less pronounced aggregation in the subsoil, too.

CONCLUSIONS

Three different kinds of organic matter and their effects on the water stability of aggregate size fractions were investigated by a new proposed wet-sieving method. The new method uses two different pretreatments: (1) fast wetting (S), which disrupts the aggregates to the highest extent and therefore produces the lowest aggregate mass, and (2) slow wetting (C), which disrupts the aggregates to the lowest extent and therefore achieves the highest aggregate mass.

The stability of aggregates caused by the strength of the adhesive forces highly depends on the size of the aggregates (Voronin and Sereda 1976). With increasing aggregate size, the strength of these adhesive forces is decreasing, and therefore the stability of the aggregates decreases (Tisdall and Oades 1982). Therefore, aggregate-stabilizing effects are more expressed and better developed on the smaller particle sizes. The smaller the aggregate fraction is, the higher ability it has to resist the same disrupting forces. The stability of microaggregates is very high because of the persistent binding agents such as aromatic humic material associated with amorphous iron (Fe) and aluminium (Al) compounds. The stability of macroaggregates is lower because they are stabilized by transient or temporary binding agents, such as roots, hyphae, and microbial- and plant-derived polysaccharides. In our investigation, adding different kinds of organic matter increased the stability of macroaggregates compared to the no-organic-matter-added control treatment, but these newly formed bindings were easily broken up by the higher disruptive force (S pretreatment). Therefore, our experiment did not result 2000–7000 μm large macroaggregate fraction in the more disruptive S treatment but detectable mass in the C pretreatment. With this S pretreatment, we got approximately half the mass of the 250–2000 μm small macroaggregate fraction but more 53–250 μm microaggregation fraction and <53 μm silt and clay fraction compared to the C pretreatment. This approves the aggregate hierarchy theory (Oades and Waters 1991) that the higher hierarchical ordered and less water-stable macroaggregate fractions disperse into smaller but more stable 53–250 μm microaggregate fractions and <53 μm silt and clay fraction.

The less disruptive C pretreatment resulted in detectable mass of the 2000–7000 μm large macroaggregate fraction and greater 250–2000 μm small macroaggregate fraction compared to the S pretreatment.

Therefore, mass of the 53–250 μm microaggregate and the $<53 \mu\text{m}$ silt and clay fraction has decreased.

The theory that the water stability of 53–250 μm microaggregate fraction is highest has been proved by all the differently disruptive pretreatments, in both depths and for all the added organic-matter treatments.

Three different kinds of organic matter were investigated: (1) maize stem (M), (2) wheat straw (W), and (3) maize stem and wheat straw (MW). Harris, Chesters, and Allen (1966) and John et al. (2005) reported $M > W$ order of enhancing aggregation. Martens (2000) reported lower decomposability but persisting aggregate stabilizing effect of maize, therefore, we expected the $M > W$ order in stabilizing of aggregates.

In our experiment, the clear trend of increased macroaggregate stability is visible in the two macroaggregate fractions. This is remarkable mainly in the upper layer, in the case of the C pretreatment. This is similar to the results of Martens (2000), who described increase in the water stability of aggregates in the 2–4 mm and >4 mm macroaggregate fractions caused by M residue incorporation. The explanations of our results are that the crop residues were mixed to the upper layer and therefore could not have affected the lower one. Further the addition of different kinds of organic matter has increased the stability of macroaggregates compared to the no-organic-matter-added control treatment, but these newly formed bindings were easily broken up by the higher disruptive force (S pretreatment). Mass of the 2000–7000 μm large macroaggregate fraction has decreased in the $MW > M > W$ order. Furthermore, adding organic materials has decreased the mass of the 53–250 μm microaggregate fraction in all treatments and depth layers in addition to both pretreatments. The 53–250 μm microaggregate fraction has dispersed into the $<53 \mu\text{m}$ silt and clay fraction in the case of S pretreatment and rested part of the bigger sized macroaggregate fractions in the case of C pretreatment. This proves that adding organic matter enhances the transient and temporary binding agents between microaggregates grouped into macroaggregates. Our results are parallel those of Martens (2000), who reported decrease in mass of the <2 mm aggregate fractions using 4-, 2-, 1-, 0.5-, and 0.25-mm sieves caused by M residue incorporation.

The different decomposable organic matters enhanced the water stability of aggregates in the following order: $MW > M > W$.

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