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# HUMIC SUBSTANCES

## Molecular Details and Applications in Land and Water Conservation

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## Chapter 16

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### SOIL ORGANIC MATTER AND AGGREGATE STABILITY AFFECTED BY TILLAGE

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#### 16.1. INTRODUCTION\*

Interaction between crop and soil management practices and soil conditions often are clouded by variability within a system. Further, causal relationships between management and soil quality are difficult to extrapolate from one region to another because of differences in soil type, climate, and management norms. The quantity and quality of soil organic matter (SOM) provides an important diagnostic link between management and sustainability of soil function.

Considerable research has been conducted on relationships among cropping sequence, soil organic matter and various biological and physical soil properties. It is generally accepted that crop production alone has caused a decline in SOM compared to the original grassland levels throughout the Great Plains [1-3]. Tillage has caused soil C losses from 28 to 77%, depending on geographic location (climate) and soil type [4]. Summer fallow, an agricultural practice to conserve

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\* **Abbreviations:** **AM**, arbuscular mycorrhizal fungi; **ANOVA**, analysis of variance; **BD**, soil bulk density; **BF**, basidiomycetes fungi; **BFpost**, basidiomycete fungi assay on soil following wet sieving; **BFpre**, basidiomycete fungi assay on soil before wet sieving; **C**, carbon; **C:N**, carbon to nitrogen atomic ratio; **CT**, chisel tillage; **DASD**, dry aggregate size distribution; **EC**, soil electrical conductivity; **ELISA**, enzyme-linked immunosorbent assay; **HA**, humic acid; **IRTG**, immunoreactive total glomalin; **MWD**, mean weight diameter; **N**, nitrogen; **NT**, no tillage; **p-value**, probability test statistic; **POM**, particulate organic matter (fine = 0.5 - 0.053 mm and coarse = 2.0 - 0.5 mm); **SOC**, soil organic carbon; **SOM**, soil organic matter.

water, in the crop sequence such as wheat-fallow crop has been implicated as an additional cause of serious declines in SOM [2,5,6] compared to annual cropping systems.

Soil organic matter influences soil compactibility, friability, soil water-holding capacity, air and water infiltration, nutrient conservation and soil permeability [7]. Boyle et al. [8], in a review of the influence of SOM on soil aggregation and water infiltration, concluded that SOM has a disproportionate effect on soil physical behavior. Hudson [9] reported soils high in SOM have greater available water-holding capacity than soils of similar texture with less SOM. Bauer and Black [10] found that a decline in SOM did not change the available water-holding capacity of moderately coarse-textured soils but increased the available water-holding capacity in medium and fine textured soils because of an increase in soil bulk density (BD). Bruce et al. [11] determined that increased phytomass input to a loamy sand increased aggregate stability and water infiltration. On long-term tillage, residue management, and N-fertility plots Pikul and Zuzel [12] reported that an increase in SOM increased the porosity of surface crusts in a silt loam. In contrast, Mulla et al. [13] were not able to establish a relation between SOM and physical behavior of a Naff silt loam, although surface crusting was observed on the "conventional" but not on the "alternative" farm. The "alternative" farm studied by Mulla et al. [13] used a cropping system that was more diverse than the "conventional" farm. However, tillage was used on both farms. Soane [14] reported that soil compaction was sensitive to small changes in SOM contents and generally decreased with increasing SOM. Adams [15] and Hudson [9] found that a 2% decrease in SOM increased BD by  $0.1 \text{ Mg m}^{-3}$  or more. Maintenance of SOM seems to be a key to sustaining soil resources and crop productivity [16].

Water stability of soil aggregates depends on the quality of organic materials [17]. Degens [18] provides a review of the function of labile organic bonding and binding agents related to soil aggregation. Soil organic carbon (SOC) accounted for 70 to 90% of the variability in soil aggregate stability of a clay loam soil [19]. Wright and Upadhyaya [20] evaluated thirty-seven soils from four geographic areas in the U. S. for the presence of glomalin, a glycoprotein exudate from arbuscular mycorrhizal fungi. They found a positive correlation of soil aggregate stability with glomalin content. Gale et al. [21] found evidence that in no till, aggregate formation is directly related to root-residue decomposition and POM C dynamics. Johnson et al. [22] found that crude humic acid and aggregate stability of a Langhei clay loam could be increased with the addition of the by-product of corn stover fermentation, which is about 70% lignin. These reports show the dynamic nature of the biological and chemical interactions that likely interplay in aggregate formation. Resolution of this issue will require characterizing field soil physically, chemically and biologically in relation to soil aggregation.

There is poor understanding of the effect of soil and crop management on the composition of SOM in agricultural soils. However, recently there have been important research contributions showing, even in the short-term, that the process of humification under different agricultural systems results in unique chemical constituents of humic materials. Ding et al. [23] investigated the chemical composition of SOM in a Norfolk loamy sand following 20 years of tillage. They showed that the composition of humic acid under conventional tillage (multiple passes with disk, cultivate, and in-row subsoiling) was less aliphatic and more aromatic than humic acid developed under conservation tillage (in-row subsoiling). Bird et al. [24] showed that on a Willows clay, the humic acid and SOM light

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fraction represent the primary active sink and source of sequestered N, affecting both short-term and long-term soil fertility. On upland, arable calcari-chromic luvisols in Estonia, Reintam et al. [25] found a decrease in the content of C and N and an increase in oxygen content of humic acids developed during three decades of agricultural management. Stearman et al. [26] found that on a Loring silt loam, humic acid under no tillage (treatments with larger amounts of C) had greater aliphatic to aromatic ratios and suggested that this characteristic might be due to earlier stages of decomposition.

Our objectives were to determine the effect of tillage on components of SOM and the stability of soil aggregates in a silty clay loam.

## 16.2. MATERIALS AND METHODS

### 16.2.1. Field Site and Sampling

Our study was conducted on the boundary between two farms. Along the boundary, soil forming factors such as weather, slope, slope position, and parent material were the same. One farm chiseled and disked fields each fall (CT), and the other farm used no tillage (NT). On the NT farm, primary tillage was last used in 1992. Under CT, corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] were row cultivated each year. The farms were located about 24 km SE of Brookings, South Dakota. Crop rotation on each farm was corn-soybean and both farms were in the same crop phase of the rotation each year.

The soil is a Vienna-Brookings silty clay loam complex (Fine-silty, mixed, superactive, frigid Aquic Hapludoll and fine-loamy, mixed superactive, frigid Calcic Hapludoll) on a 0.6% slope. On each farm, four replications were established at two slope positions (near-summit and near-toe-slope positions). Slope positions were about 480 m apart.

To measure soil-profile properties, triplicate soil cores, 32 mm in diameter, were taken from each farm and each replicate at 80 mm increments from the top 240 mm in fall 2001. Soil BD, C, C:N, pH, electrical conductivity (EC), and soil texture were measured for these samples. Soil pH and EC were measured using a 1:1 soil to water mixture. Volumetric soil carbon was calculated as the product of SOC concentration, bulk density, and sample increment.

For determining properties of soil aggregates, about 10 kg of soil was collected from the surface 50 mm in spring and fall 2002. Both farms were in soybean. Soil was collected using a flat scoop from both crop-row and between-row positions in spring 2002 and from two slope positions in fall 2002. After air drying, soil aggregates were separated into six size groups using a rotary sieve [27]. Group 1 was soil <0.4 mm, group 2 was 0.4-0.8 mm, group 3 was 0.8-2 mm, group 4 was 2-6 mm, group 5 was 6-19 mm, and group 6 was >19 mm. Aggregates obtained using the rotary sieve were further processed to measure dry aggregate stability, water stability, SOC, SOM, POM, HA, glomalin and BF.

### 16.2.2. Measurements

We measured the water stability of dry aggregates to evaluate the treatment effect on soil slaking. Water stability was measured using the sieving procedure described

by Kemper and Rosenau [28]. Tests were conducted on dry aggregates from sieve groups 2, 3, 4 and 5; tests on premoistened aggregates were conducted on aggregates from sieve groups 3, 4 and 5. Duplicate measurements were made on all aggregates. Prewetting was accomplished using a humidifier [28]. Soil aggregate stability calculations were corrected for the mass of sand remaining on sieves.

Total C and N were measured by combustion using a LECO<sup>†</sup> CN 2000 analyzer (Leco Corp., St Joseph, MI). Measurements were made on both soil and HA from aggregate groups 1-6. All samples were ground and passed through a 0.5 mm sieve prior to analysis. Visible pieces of crop residue were removed prior to grinding.

Particulate organic matter was measured by dispersing and sieving using a modification of the method provided by Cambardella and Elliott [29]. Soil in aggregate groups 4, 5 and 6 was crushed and passed through a 2 mm sieve. Soil in all aggregate groups was dispersed in sodium hexametaphosphate for 24 hours, stirred with a malt mixer for five minutes, and transferred to a set of nested sieves having mesh sizes of 0.5 and 0.053 mm. Sieves were rinsed until all material smaller than the mesh size had been washed through. Material on each sieve was transferred to aluminum weigh pans, and the mass of organic material determined by loss on ignition (450°C for 4 hours). Particulate organic matter was expressed as percent of soil organic matter (SOM) in each aggregate group, where SOM was measured by loss on ignition (450°C for 4 hours).

Soil-aggregating basidiomycetes were quantified using an ELISA protocol as described in Caesar-TonThat, et al. [30] Absorbance ( $Abs_{540/655}$ ) was read at dual wavelengths of 450 nm/655 nm using a BioRad 550 microplate reader controlled by a computer with the Plate Reader Manage program (BioRad, Hercules, CA). All incubation steps were performed at room temperature on aggregate material. All samples were processed in triplicate. Two independent tests were made on each aggregate sample. Measurements were made on "whole aggregates" prior to wet sieving (BFpre) and measurements also were made on the soil retained on the sieve following the wet sieve test (BFpost).

Easily extractable glomalin, total glomalin (TG), and immunoreactive glomalin (IRTG) fractions were extracted as described in Wright et al. [31] except that a 1 g of sample was extracted using 8 mL of extraction solution. Bradford and immunoreactive protein assays were performed as described by Wright and Upadhyaya [20] and Wright et al. [32].

Soil was fractionated into humin, HA and fulvic acid (FA) fractions according to Stevenson [33]. Thirty g of soil was extracted for HA isolation. Soils were treated with 0.05 M HCl and washed with reverse-osmosis H<sub>2</sub>O to remove carbonates. After washing with HCl, the HA and FA were separated from the humin and inorganic fraction using repeated extractions with 0.5 M NaOH under N<sub>2</sub>. The humin fraction is the portion of humus that remains bound to the mineral soil after extraction with dilute alkaline solution [33]. Humin and HA fractions were freeze-dried, and dried fractions were ground and analyzed for total C and N and inorganic C.

Analysis of variance was used to determine differences among soil properties and between aggregate size groups. Linear regression and multiple linear

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<sup>†</sup> Mention of trade names is for the benefit of the reader and does not constitute endorsement by the USDA over other products not mentioned.

regressions (best sub-sets) were used to identify those soil properties most important to the prediction of water stability.

## 16.3. RESULTS AND DISCUSSION

### 16.3.1. General Site Characteristics

There were no differences in soil texture between farms. The soil was a clay loam, on a 0.6 % slope, having 340 g kg<sup>-1</sup> clay and 260 g kg<sup>-1</sup> sand (data not shown). Under NT, bulk density for soil depths of 0-80, 80-160, and 160-240 mm was significantly greater at each depth compared with CT by 9 to 12% (Table 16.1). Soil C distribution was stratified with depth as would be expected according to the tillage method.

**Table 16.1** Analysis of variance of soil properties at depths of 0-80, 80-160 and 160-240 mm under no tillage (NT) and chisel tillage (CT) treatments. Soil cores collected after soybean planting in spring 2002

Soil property and tillage system	Soil depth (mm)		
	0-80	80-160	160-240
Bulk density		g cm <sup>-3</sup>	
NT	1.18	1.39	1.46
CT	1.05	1.24	1.34
p-value	0.028	0.002	0.002
Organic carbon		g kg <sup>-1</sup>	
NT	31.0	23.7	22.9
CT	29.4	26.2	23.3
p-value	0.05	0.005	ns <sup>a</sup>
Carbon to nitrogen ratio			
NT	10.8	10.5	10.5
CT	10.5	10.2	10.2
p-value	0.028	ns	ns
Soil pH			
NT	6.6	6.4	6.8
CT	6.3	6.2	6.6
p-value	ns	ns	ns
Electrical conductivity		dS m <sup>-1</sup>	
NT	0.396	0.295	0.308
CT	0.360	0.306	0.316
p-value	ns	ns	ns

<sup>a</sup> ns = not significant

Soil organic carbon profiles (Table 16.1) show that there was a greater concentration of C and a wider C:N in the top 80 mm under NT compared with CT. At the 80 to 160 mm depth, SOC was higher under CT compared with NT. These

profiles probably reflect differences in residue placement between tillage treatments. In the case of NT, all residues remained on the surface. Under CT, enriched SOC at the 80 to 160 mm depth, when compared to NT, suggests residue incorporation [34] at this depth. In the top 240 mm, volumetric SOC under NT was 8% greater ( $p = 0.05$ , data not shown) than under CT. The C:N ratio of the NT was 3% higher in the surface 80 mm compared to the CT, likely reflecting the accumulation of residue at the surface. There were no differences in soil pH or EC between treatments (Table 16.1).

### 16.3.2. Soil Aggregate Stability

**Dry Aggregate Distribution and Stability.** The erodible fraction (EF) is defined as the percentage of soil mass with aggregates  $< 0.84$  mm diameter, and this parameter has been related to soil wind erodibility. Merrill et al. [35] have shown that EF was more sensitive to soil management effects than indices describing aggregate size distribution (such as MWD). We found differences in the distribution of dry aggregates between tillage treatments and sampling date. Further, there was a significant interaction between tillage and sample time (Two-way analysis of variance shown in the lower portion of Table 16.2). However, inspection of one-way analysis of variance for time of sampling (Table 16.2, upper portion) shows that, under NT, the distribution of aggregates did not change with sampling time. The significant interaction of tillage and time is largely a consequence of CT.

Under CT, we found a significant increase in the mass of aggregates in size groups 1 through 4 collected in the fall 2002 compared to soil collected in spring 2002 (Table 16.2, one-way ANOVA). In contrast, NT resulted in a dramatic shift in the distribution of aggregate size class such that there was a greater mass of soil in class 6 compared with the smallest aggregate sizes (Table 16.2, two-way analysis of variance). We speculate that the change in aggregate distribution (greater mass of large aggregates under NT) might be explained by the accumulation of root biomass and root exudates under NT consistent with the findings of Gale et al. [21,36]. New aggregation under CT would be disrupted by annual fall tillage.

Soil in groups 1 and 2 are susceptible to wind erosion [35] and both farms were in soybean during 2002. In northern, sub-humid regions of the Great Plains, wind and water erosion are persistent problems. Potential soil losses may be less than other erosion-prone hot spots. For example, in the United States, the southern Great Plains are the soil wind erosion hot spots [37]. However, regardless of the quantity of soil eroded, the consequences are the same. Erosion removes the best quality soil first. Fine soil particles lost to erosion are the richest in organic matter and nutrients. Soil conservation practices that improve soil aggregate stability also help to retard soil loss by maintaining surface conditions resistant to weather vagaries.

There were no differences in DASD between samples collected on row or between row in spring 2002 (data not shown). Further, there were no significant differences in DASD between samples collected up or down slope on respective farms (data not shown).

Multiple passes of aggregates through a rotary sieve provides a sensitive way to test for dry aggregate stability [27]. With a second sieving, aggregates under CT had a greater tendency to abrade into small aggregates (groups 1 and 2) when compared with NT (Table 16.3, change in mass following second sieving). The increase in mass within groups 1 and 2 indicates that aggregates from CT degraded

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**Table 16.2** Dry aggregate size distribution (DASD) under no tillage (NT) and chisel tillage (CT) treatments. Dry aggregate size distributions were measured on soil collected from the top 50 mm after soybean planting (spring) and before soybean harvest (fall) in 2002. Group 1 was soil <0.4 mm, group 2 was 0.4-0.8 mm, group 3 was 0.8-2 mm, group 4 was 2-6 mm, group 5 was 6-19 mm, and group 6 was >19 mm

	Aggregate group					
	1	2	3	4	5	6
DASD (g kg <sup>-1</sup> )						
No tillage						
spring	27	25	68	169	272	434
fall	24	23	61	145	205	540
p-value	ns <sup>a</sup>	ns	ns	ns	0.006	0.020
Chisel tillage						
spring	106	73	104	132	232	349
fall	152	102	134	160	244	205
p-value	0.001	0.001	0.001	0.001	ns	0.001
Average DASD (g kg <sup>-1</sup> )						
Tillage & time						
NT	26	24	65	157	238	487
CT	129	88	119	146	238	277
Spring	67	49	87	150	252	391
Fall	89	62	98	152	224	373
p-value tillage	0.001	0.001	0.001	ns	ns	0.001
p-value time	0.006	0.001	0.030	ns	0.012	ns
p-value interaction	0.003	0.001	0.001	0.009	0.001	0.001

<sup>a</sup> ns = not significant

**Wet Aggregate Stability.** Water stability of both dry and pre-moistened aggregates was greater under NT compared with CT (Table 16.3), and these results corroborate our dry aggregate stability tests. There were no differences in soil forming factors or soil texture between farms, and consequently we hypothesize that the binding agents responsible for increased stability under NT developed as a consequence of no tillage management over a period of about ten years. These two tests of stability (dry and wet) indirectly provide clues as to the nature of the aggregate binding agents. Kemper and Rosenau [28] described a process of soil drying whereby soluble compounds such as silica, carbonates, and organic molecules concentrate and precipitate at particle-to-particle contacts to cement aggregates together. Differences between treatments are more pronounced (NT had about 50 % greater stability than CT) for tests of water stability using dry aggregates (Table 16.3), and this may indicate a greater concentration of water soluble binding agents present under NT.

Water stability of dry aggregates increased ( $p < 0.001$ ) with aggregate size on both the NT and CT farms (ANOVA among sieve sizes not shown). Tisdall and Oades [17] and Tisdall et al. [38] proposed a hierarchical structure of aggregate formation whereby small aggregates bind to form larger aggregates. Further, the

binding agents within small aggregates, termed microaggregates by Tisdall and Oades [17], are different from those that bind microaggregates into macroaggregates. Data in Table 16.3 are an average for samples collected on and off row. There were no significant differences in water stability (dry or premoistened aggregates) due to row position (data not shown).

**Table 16.3** Dry stability and water stability of soil aggregates collected from the top 50mm in spring 2002 from the no tillage (NT) and chisel tillage (CT) farms. Change in mass following second sieving is an indicator of dry aggregate stability (negative value indicates loss of soil from that group). Group 1 was soil <0.4 mm, group 2 was 0.4-0.8 mm, group 3 was 0.8-2 mm, group 4 was 2-6 mm, group 5 was 6-19 mm, and group 6 was >19 mm

	Aggregate group					
	1	2	3	4	5	6
Tillage	Change in mass following second sieving (g kg <sup>-1</sup> )					
NT	9.72	6.09	11.4	17.9	9.70	-54.5
CT	26.6	11.2	7.99	6.00	-6.70	-46.5
p-value	0.001	0.001	0.004	0.001	0.002	0.091
	Water stability <sup>a</sup> of dry aggregates (%)					
NT	nm <sup>b</sup>	20.3	27.8	38.0	55.8	nm
CT	nm	9.8	15.3	15.9	28.0	nm
p-value		0.001	0.001	0.001	0.001	
	Water stability <sup>a</sup> of premoistened aggregates (%)					
NT	nm	nm	87.2	91.0	92.4	nm
CT	nm	nm	81.0	78.7	87.7	nm
p-value			0.01	0.003	ns <sup>c</sup>	

<sup>a</sup> average water stability of soil aggregates collected on row and between row. Mean values of water stability for each treatment and size group represent sixteen measurements (8 plots and duplicate determinations on each plot); <sup>b</sup> not measured; <sup>c</sup> not significant.

### 16.3.3. Soil Aggregate Properties

**Aggregate Carbon and Nitrogen.** We evaluated spatial variability within our field sites by sampling on and off row and sampling two slope positions. For samples collected in spring 2002, we found no differences in SOC of aggregates collected on or off row (data not shown). On the CT farm, we found no differences in SOC of aggregates due to slope position in fall 2002. Under NT, we found a significant difference in SOC of aggregates between slope positions in fall 2002 (data not shown). Only results for samples collected from upslope positions of both NT and CT are reported hereafter.

Ten years of NT had a significant ( $p \leq 0.01$ ) effect on SOC in all aggregate groups (Table 16.4). Average SOC of aggregates under NT was 32.3 g kg<sup>-1</sup> compared with 29.6 g kg<sup>-1</sup> under CT. Further, there was a difference ( $p \leq 0.001$ ) in SOC among soil aggregate groups on both farms (data not shown). Soil organic carbon was not uniformly distributed among soil aggregate groups; the greatest concentration of SOC was in soil aggregate group 3 under both tillage systems (Table 16.4).

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The carbon to nitrogen ratio was significantly greater under NT compared with CT for all aggregate groups (Table 16.4). The average C:N ratio of aggregates was 10.7 under NT and 10.2 under CT. There was a significant difference in C:N among soil aggregate groups and treatments, but no correlation among aggregate size and treatments (two-way analysis of variance not shown). Under NT, the widest C:N was for aggregates in group 3, whereas under CT the widest C:N was for aggregates in group 4 (Table 16.4). There were no differences in SOC of aggregates due to time of sampling (spring or fall) except within aggregate group 4. The effect of sample time is likely due to small variations within each field.

**Table 16.4** Carbon and the atomic ratio C:N under no tillage (NT) and chisel tillage (CT) treatments. Measurements were made on soil collected from the top 50 mm after soybean planting (spring) and before soybean harvest (fall) in 2002. Group 1 was soil <0.4 mm, group 2 was 0.4-0.8 mm, group 3 was 0.8-2 mm, group 4 was 2-6 mm, group 5 was 6-19 mm, and group 6 was >19 mm

	Aggregate group						Ave.
	1	2	3	4	5	6	
	Total C (g kg <sup>-1</sup> )						
NT	32.4	32.8	34.4	33.2	31.0	30.1	32.3
CT	29.5	29.7	31.0	30.2	28.8	28.4	29.6
p-value tillage	0.01	0.00	0.007	0.001	0.007	0.01	0.001
p-value time	ns <sup>a</sup>	ns	ns	0.003	ns	ns	ns
p-value aggregate							0.001
	C:N						
NT	10.6	10.7	10.8	10.7	10.6	10.6	10.7
CT	10.2	10.1	10.3	10.4	10.1	10.2	10.2
p-value tillage	0.02	0.00	0.001	0.001	0.004	0.00	0.001
p-value time	ns	0.02	ns	ns	ns	ns	ns
p-value aggregate							0.001

<sup>a</sup> not significant

**Particulate organic matter.** Soil organic matter is composed of material varying in chemical composition and degree of decomposition. Particulate organic matter is physically defined as the organic material isolated in the fraction 0.053 to 2.00 mm. It is an intermediate between fresh plant litter and humified SOM, and has been shown to be more sensitive to changes in management than total SOM [39]. In undisturbed soils, POM is derived primarily from roots [21,36]. New microaggregates are thought to form around decomposing pieces of root-derived POM inside macroaggregates [36].

Average SOM of aggregates was greater ( $p < 0.001$ , Table 16.5) under NT (78.1 mg g<sup>-1</sup>) compared with CT (75.4 mg g<sup>-1</sup>). Although this is a small increase (3%), it is notable because measurable changes in SOM occur slowly. Further, there were differences ( $p \leq 0.001$ ) in SOM among soil aggregate groups (Table 16.5), with soil aggregate group 3 under NT and aggregate group 4 under CT having the greatest concentrations. Measurements of SOM corroborate our SOC results and further show that organic materials are not uniformly distributed across all aggregate sizes. For both SOC and SOM, the greatest concentration was found in

mid-sized aggregates. However, this was not the case for the distribution of POM.

**Table 16.5** Soil organic matter (SOM), fine particulate organic matter (POM), and total POM under no tillage (NT) and chisel tillage (CT) treatments. Aggregate group 1 was soil <0.4 mm, group 2 was 0.4-0.8 mm, group 3 was 0.8-2 mm, group 4 was 2-6 mm, group 5 was 6-19 mm, and group 6 was >19 mm

	Aggregate group						Ave.
	1	2	3	4	5	6	
	SOM (mg g <sup>-1</sup> )						
NT	76.4	74.6	83.8	82.0	76.9	74.6	78.1
CT	76.6	75.1	78.1	79.3	72.0	71.5	75.4
p-value tillage	ns <sup>a</sup>	ns	0.002	ns	0.039	0.060	0.001
p-value							0.001
	Fine POM (0.053 – 0.5 mm) as percent of SOM						
NT	20.1	13.3	13.4	16.2	15.1	12.3	15.1
CT	16.2	9.0	9.1	11.5	10.5	9.6	11.0
p-value tillage	0.022	0.002	0.001	0.001	0.001	0.053	0.001
p-value							0.001
	Total POM (0.053 – 2.0 mm) as percent of SOM						
NT	23.2	23.0	23.4	20.8	17.3	14.1	20.3
CT	17.8	14.0	17	18.8	12.4	10.6	15.1
p-value tillage	0.015	0.001	0.004	ns	0.003	0.043	0.001
p-value							0.001

<sup>a</sup> not significant

Fine POM (0.053 – 0.5 mm) comprised a greater fraction of total POM than coarse POM (0.5 – 2.0 mm) for both NT and CT (Table 16.5). In Table 16.5, POM is expressed as a percentage of SOM and it is important to note that there were no differences in SOM between NT and CT within aggregate groups 1 and 2 (Table 16.5). However, the greatest concentration of POM was measured within the smaller aggregate groups, and the greatest differences in POM (fine and total) between NT and CT were found in the smaller aggregate groups. Average fine and total POM were significantly ( $p \leq 0.001$ ) greater under NT (Table 16.5), and fine POM was significantly greater under NT compared with CT in all aggregate groups. Although there was more fine POM and total POM under NT compared to CT, the distribution of fine and total POM among the aggregate size groups was similar under both tillage systems (for example, both had the high concentration of POM in the smallest aggregate size group, Table 16.5). Greater concentration of POM in the undisturbed soil of NT might be a consequence of an accumulation of less decomposed root materials as described by Gale et al. [21,36].

**C:N of Humic Acid.** Humic materials are important soil binding agents, and we analyzed C:N of HA to see whether there were gross differences in the composition of HA between the two tillage systems and among aggregate groups. Generally, it is accepted that the C:N ratio of surface soils under NT will be wider than under tillage and our average C:N of soil aggregate groups (Table 16.4) shows that this is

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the case. Stevenson [33] has suggested a relation between organic matter decomposition and C:N of HA such that conditions that encourage decomposition (mixing and aeration provided by tillage) result in a narrowing of the C:N of HA. Chefetz et al. [40] found evidence obtained by analysis of HA that “coarse size” aggregates contained freshly deposited organic matter and thus should be expected to have a wider C:N ratio. Coarse aggregates had C:N of HA of 12.3 and fine aggregates had C:N of 10.5. The “coarse aggregates” evaluated by Chefetz et al. [40] roughly correspond to the smallest aggregate group of our study.

The average C:N of HA under NT was significantly different compared with HA under CT. Further, there were significant differences among aggregate groups (Table 16.6) and a trend for the smallest aggregate groups to have the widest C:N ratios (11.2 under NT compared with 11.0 under CT). We think that the difference in C:N ratios among aggregate groups provides evidence to suggest that “less humified” materials are found within the smaller aggregates having the wider C:N ratios.

**Table 16.6** Carbon to nitrogen ratio (C:N) of humic acid, glomalin, and basidiomycete assay of soil aggregates under no tillage (NT) and chisel tillage (CT) treatments. Basidiomycete assay was conducted on material retained on sieve following wet sieving (BFpost). Aggregate group 1 was soil <0.4 mm, group 2 was 0.4-0.8 mm, group 3 was 0.8-2 mm, group 4 was 2-6 mm, group 5 was 6-19 mm, and group 6 was >19 mm

	Aggregate group						Ave.
	1	2	3	4	5	6	
	C:N of humic acid						
NT	11.2	11.0	10.4	10.4	10.5		10.7
CT	11.0	10.9	10.2	10.3	10.3		10.5
p-value tillage	ns	ns	ns	ns	0.006		0.001
p-value aggregate							0.001
	Immunoreactive glomalin (mg g <sup>-1</sup> )						
NT	0.52	0.55	0.58	0.57	0.54	0.58	0.56
CT	0.44	0.48	0.46	0.48	0.46	0.44	0.46
p-value tillage	ns	ns	ns	ns	ns	ns	0.003
p-value aggregate							ns
	Basidiomycete assay						
NT			0.757	0.519	0.474		0.583
CT			0.532	0.506	0.429		0.489
p-value tillage			0.018	ns	ns		0.003
p-value aggregate							0.001

**Soil Fungi.** Our study investigated the effect of two common soil fungal groups on soil aggregation. Basidiomycete fungi occupy aerobic sites and are responsible for the degradation of cellulose and lignin in non-living organic matter. Polysaccharide exudates from this group of fungi are important in soil aggregation, but are short lived as binding agents. Arbuscular mycorrhizal (AM) fungi are termed endomycorrhiza and they live in symbiotic association with plants. This fungal

group produces an exudate called glomalin, which is a stable, iron-containing glycoprotein [32] important in soil aggregation [31]. Further, Nichols [41] has shown that POM also contains substantial amounts of glomalin, and this finding may help to explain why fine POM is strongly associated with soil aggregation.

The average concentration of IRTG was significantly greater under NT compared with CT, but differences could not be detected when comparing between individual groups (Table 16.6). The concentration of IRTG was the same among aggregate groups for both NT and CT (Table 16.6). The immunoreactive component of glomalin in soil is considered to be recently deposited and has been shown to be highly correlated with exudates of AM fungal hyphae [42].

The average number of soil-aggregating basidiomycetes (BFpost) in soil left following wet sieving was significantly greater under NT compared with CT. Further, there were significant differences among aggregate groups (Table 16.6) and a trend for the smallest aggregate groups to have the greatest absorbance value (absorbance for BFpre not shown). Polysaccharide exudates from basidiomycete fungi are important in soil aggregation. We do not have independent measurements of polysaccharide exudates; however, we assume that a high absorbance value reflects a high concentration of polysaccharide material from BFpost.

**Regression Modeling.** Linear regression indicated water stability of dry aggregates was correlated with fine POM ( $p = 0.003$ ), coarse POM ( $p = 0.032$ ), C:N of HA ( $p = 0.003$ ) and BFpre ( $p = 0.024$ ), but not with other soil parameters SOM, SOC, total N, soil C:N, concentration of HA, BFpost, IRTG, or IRTG:TG (using a minimum of  $p = 0.1$ ).

Use of multiple regression modeling allows identification of the best predictors from a given dataset. This present data set is unique in that it has characterized SOM biologically (IRTG, BFpre, BFpost), chemically (HA and C:N of HA) and physically (POM and fine POM). Biological constituents represent the role of fungi, POM primarily is intermediate decomposed plant material and HA is a component of stable SOM. A narrow C:N ratio of HA may indicate more advanced decomposition. The best single-component predictor of aggregate stability was fine POM ( $r^2 = 0.34$ ). The best two-component model included fine POM and BFpre ( $r^2 = 0.55$ ). The best three-component model included fine POM, C:N of HA, and BFpre. This model accounted for 63% ( $p < 0.001$ ) of the variability in water stability of dry aggregates (Figure 16.1). There was little improvement in prediction of aggregate stability from including additional parameters.

Our findings support the hypothesis that stable aggregate formation is of a dynamic nature that reflects biological, chemical and physical interactions. A conceptual model by Six et al. [43] of an aggregate 'life cycle' proposed that fine intra-aggregate POM is formed as it becomes encrusted with clay particles and microbial products, and forms within macroaggregates. As macroaggregates degrade, stable microaggregates become the nucleus for the formation of new macroaggregates. Such models are helpful but need to be expanded to include root exudates, microbial products, various POM fractions and humified material. Furthermore, the function of physical, biological or chemical binding agents within different aggregate size groups needs to be defined.

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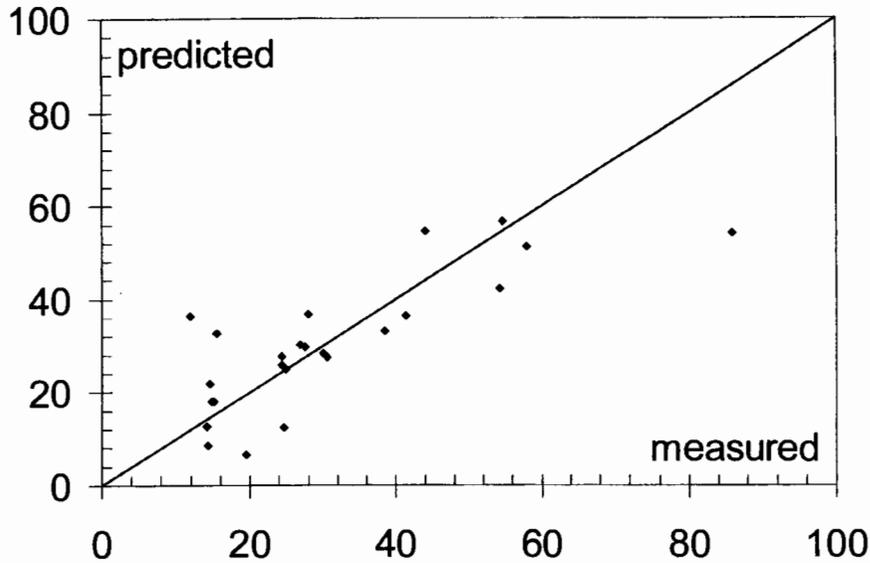
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**Figure 16.1** Relation of measured water stability and predicted water stability of soil aggregates (data pairs) and a 1:1 line. Predicted values of water stability (WS) were based on predictors of fine POM (FPOM), C:N of humic acid (C:N HA), and basidiomycete assay before sieving (BFpre), providing the following relation:  $WS = -388 + 2.69 \text{ FPOM} + 35.4 \text{ C:N HA} + 61.4 \text{ BFpre}$

## 16.4. CONCLUSIONS

Wind and water erosion are persistent problems in northern sub-humid regions of the Great Plains. Soil conservation practices that improve soil aggregate stability also help to retard soil loss by maintaining surface conditions resistant to weather vagaries. Long term field experiments on comparable soil located in close proximity provide a unique and valuable opportunity to compare divergent management strategies. The adjacent farm fields used in this study were under two different tillage management strategies for ten years and were in the same rotation phase. We think that improved soil aggregation and increased surface cover of NT compared to CT will help to keep top soil in place. The multifaceted approach to characterizing SOM as it relates to soil aggregate formation helped to identify how different components of SOM interact to improve soil aggregation. Differences in properties among aggregates show that organic cementing agents (humic materials or microbial exudates) are not uniformly distributed among aggregate groups. Our results show improved soil aggregation as a consequence of no tillage farming when compared to tillage.

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