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Influence of conservation tillage in onion production on the soil organic matter content and soil aggregate formation**

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A b s t r a c t. In a field experiment with conservation tillage for onion production the influence of various methods of pre-winter and pre-sowing tillage (conventional tillage, no tillage, and disking) as well as the biomass of the intercrop plants on the soil organic matter content and soil aggregate formation were studied. *Secale cereale* and *Vicia sativa* grown as intercrop cover plants favourably influenced the soil aggregation. It was expressed by lower cloddiness and pulverization of soil in comparison with conventional tillage, without plant mulches. Leaving the mulch from cover plants on the soil surface from autumn to spring increased the proportion of macroaggregates (∅ 0.25-10 mm). The positive influence of plant mulches was mainly observed after winter and in the initial period of onion vegetation. The changes in soil aggregation under the influence of mulching cover plants and simplifications of the soil tillage system for vegetables occurred mainly in the soil arable layer (0-20 cm).

K e y w o r d s: soil aggregation, cover plants, mulch, disking, no tillage

INTRODUCTION

The state of aggregation determines the water-air relations in soil and influences the thermal conductivity, porosity and density of soil, availability of nutrients, as well as biological processes, *etc*. (Błażewicz-Woźniak *et al.,* 2001; Bronick and Lal, 2005; Lipiec *et al.*, 2007; Witkowska-Walczak *et al.*, 2004). Once the elementary soil particles form aggregates, the soil aggregate structure is created. The formation of soil aggregate structure is a function of the mineral composition, the organic matter content, the degree of saturation of the sorption complex with both mono- and bivalent ions, and biological activity. The aggregates ability to maintain a given size and shape (stability) is conditioned by the presence of binding forces in the soil, which link the elementary soil particles into microaggregates, and later into meso- and macroaggregates. The role of binding agents is played by soil colloids (clay minerals and organic compounds), water, bacterial exudates, and the exudates of soil fauna and of the roots of higher plants. Organic matter exerts the strongest influence on formation and stabilization of soil aggregates (Barral *et al.*, 2007; Dexter, 1988; Liu *et al.*, 2005; Walczak and Witkowska, 1976; Yang *et al.*, 2007). A special role is played by humic acids which coagulate in soil under the influence of hydrogen ions (acid humus) and ions of Mg^{2+}, Ca^{2+} (humus of a mull form) as well as polysaccharides and polyuronides present in bacterial exudates, which create a net of fibers between the non-organic particles of soil and bind them together (Dąbek-Szreniawska, 2004; Martin 1971; Tisdall, 1996). Soil microorganisms also play an important role in the formation and stabilization of soil aggregates (Dąbek-Szreniawska *et al.*, 2002; Lynch and Bragg, 1985). Therefore, maintaining their constant activity in the vegetative period is one of the basic principles of organic farming, of which an important element is conservation tillage (Granstedt and Tyburski 2006; Kuś 1995; Piekarz and Lipiec 2001).

The aim of this work, which is part of a larger study, was evaluation of the effect of cover crop plants and varied pre-winter and spring pre-sowing tillage applied for onion on the soil organic matter content and soil aggregate formation.

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MATERIALS AND METHODS

A field experiment was done in the years 2003-2006 at the Felin Experimental Station of the University of Life Sciences in Lublin, Poland (51°23'N, 22°56'E), on a grey-brown podzolic soil derived from loess, overlying chalk marl, with a grain size distribution typical for medium silt loam. In the experiment the pH of the soil varied from 4.87 to 6.09 pH. In the plough layer (0-20 cm), the following were determined (mean values): 11.59-12.79 mg P, 15.02-20.69 mg K and 8.68-10.43 mg Mg 100 g^{-1} of soil (Błażewicz-Woźniak *et al.,* 2008).

The experimental plant was onion (*Allium cepa* var. *cepa* Helm.) of the Wolska variety. The experiment was set up according to the method of random sub-blocks with four replications. The following factors were included: mulching cover plants (spring rye, *Secale cereale,* and spring vetch, *Vicia sativa*); various soil tillage: no tillage (NT), disking during the spring (SD), and disking before the winter (WD). The cover plants: spring rye (R) in the amount of 150 kg ha^{-1} and spring vetch (V) – 140 kg ha^{-1}, were sown in late July 2003 and in early August 2004 and 2005, in the years preceding the onion cultivation. The biomass produced was mixed with soil according to the set scheme (in the autumn or spring). During the winter the inter-crop plants left on the field frozen, and in the spring the soil was with covered with mulch. The tillage measures applied for onion are shown in Table 1. The control treatment was conventional tillage with a mouldboard plough without mulching plants (CT).

Soil samples of approximately 2 kg from the layer of 0-20 and 20-40 cm were collected for analysis of soil structure in four periods: after wintering before the beginning of spring cultivation, at the beginning of plant growth, during full vegetation, and in the period of onion harvest. In the lab the soil was air-dried, and 500 g samples were sifted through a set of sieves with the following mesh diameters: 0.25, 0.5, 1, 3, 5, 7, 10 mm. The soil aggregate composition was determined by separating the fractions with diameters of: < 0.25 mm (microaggregates), 0.25-0.5, 0.5-1, 1-3, 3-5, 5-7, 7-10, >10 mm. Classification of aggregates was conducted according to Sawinow (Walczak and Witkowska, 1976), by separating the following fractions: silt-sized aggregates with diameters < 0.25 mm; soil aggregates with diameters of 0.25-10 mm; clod formations with diameters > 10 mm. Yearly, similarly to the studies of physical soil properties, the content of organic matter (OM) in soil layers of 0-20 and 20-40 cm was determined in four periods, using the weight loss after incineration in a muffle furnace at a temperature of 550ºC. The results obtained were analyzed statistically by analysis of variance. The statistical significance of differences was determined using the Tukey's test with P = 0.05. Correlation analysis was done for selected characteristics.

RESULTS AND DISCUSSION

The good influence on the content of organic matter (SOM) had spring rye as a cover plant (Table 2). Soil in combinations with spring vetch as a mulching plant contained less SOM than soil in the plot with conventional tillage, without cover plants. The most favourable tillage variation affecting the amount of organic matter was disking before winter (WD) and with the use of the rye mulch, also the no tillage (NT), while the worst treatment appeared to be disking in the spring (SD), in particular when the cover plant was spring vetch. The lack of significant increase of SOM content while using spring vetch as a cover plant can be explained by lower biomass of these plants in comparison with spring rye (24.9 and 30.3 t ha^{-1}, respectively) (Kęsik and Błażewicz-Woźniak, 2008), as well as faster decomposition by soil microorganisms. The more vulnerable to decomposition the organic remnants are, the richer the development of soil microflora (Dąbek-Szreniawska, 2004). In the studies by Ding *et al.* (2006) organic carbon was higher in soils under both vetch/rye and rye alone management systems than under no cover crop.

The lowest content of SOM in the analyzed soil was noted after the winter (1.93%) and the highest at the time of onion harvest (2.01%). Also, Barzegar *et al.* (2004) stated that organic matter concentration measured after harvesting was generally higher than before cultivation and the organic matter concentration in different soil layer of NT, except for the upper soil layer, was significantly higher compared to

T a b l e 1. The sequence of measures in the soil tillage systems applied in the experiment conducted

Tillage systems	SF:	K:
Conventional mouldboard ploughing without cover plants	1+2+2+5	2+7+8+2+9+2
No tillage, cultivation with cover plants	3+2+4+2	10
Spring mixing of biomass with soil (spring disking), cultivation with cover plants	3+2+4+2	6+2+9+2
Mixing of biomass with soil before winter (pre-winter disking)	3+2+4+2+6	6+2+9+2

S – summer, F – fall, K – spring. 1 – skimming (6-8 cm), 2 – harrowing, 3 – medium ploughing (15-20 cm), 4 – cover plant sowing, 5 – deep ploughing (25-30 cm), 6 – disking, 7 – scarifying, 8 – rolling, 9 – onion traditional sowing, 10 – onion direct sowing.

Table 2. Influence of tillage and cover crops on content of organic matter (SOM) and percentage of soil aggregates with diameter of 0.25-10 mm in the soil layers 0-20 and 20-40 cm (mean for 2004-2006)

Treatment	Content of organic matter (SOM)					Aggregates 0.25-10 mm				
	After winter	Beginning of vegetation	Full of vegetation	At harvest	Mean	After winter	Beginning of vegetation	Full of vegetation	At harvest	Mean
					0-20 cm					
CT	2.11	2.14	2.15	2.15	2.14	43.4	44.7	48.4	49.1	46.4
NT+R	2.17	2.36	2.14	2.33	2.25	49.7	51.0	49.5	50.4	50.2
SD+R	2.16	2.29	2.18	2.27	2.22	50.2	49.4	47.6	43.6	47.7
WD+R	2.21	2.19	2.18	2.30	2.22	43.4	48.7	49.9	48.5	47.6
Mean (R)	2.18	2.28	2.16	2.30	2.23	47.8	49.7	49.0	47.5	48.5
NT+V	1.93	2.08	2.07	2.07	2.04	50.9	49.0	48.2	53.9	50.5
SD+V	1.96	2.00	2.08	2.01	2.01	49.8	47.4	45.7	47.8	47.7
WD+V	2.08	2.08	2.16	2.10	2.10	47.8	48.0	51.9	51.1	49.7
Mean (V)	1.99	2.05	2.10	2.06	2.05	49.5	48.1	48.6	50.9	49.3
Mean	2.09	2.16	2.14	2.18	2.14	47.9	48.3	48.7	49.2	48.5
					20-40 cm					
CT	1.89	1.78	1.84	1.95	1.87	48.8	57.0	52.3	43.9	50.5
NT+R	1.75	1.80	1.75	1.91	1.80	46.2	47.8	50.7	48.5	48.3
SD+R	1.67	1.89	1.82	1.91	1.82	42.4	44.6	50.9	44.8	45.7
WD+R	1.52	1.86	1.70	1.82	1.73	46.3	49.9	55.0	49.2	50.1
Mean (R)	1.65	1.85	1.76	1.88	1.78	45.0	47.4	52.2	47.5	48.0
NT+V	1.83	1.75	1.75	1.81	1.79	47.8	49.9	48.2	53.3	49.8
SD+V	1.76	1.63	1.77	1.64	1.70	43.1	55.7	54.7	50.4	51.0
WD+V	1.91	1.72	1.78	1.86	1.82	47.3	43.8	50.9	47.6	47.4
Mean (V)	1.83	1.70	1.76	1.77	1.77	46.1	49.8	51.3	50.4	49.4
Mean	1.76	1.78	1.77	1.84	1.79	46.0	49.8	51.8	48.2	49.0
LSD 0.05 for:	treatments				0.11					ns
	depth				0.03					ns
	dates				0.07					ns

CT – conventional tillage (control): pre-winter ploughing + spring pre-sowing measures, NT – no-tillage, SD – spring disc harrowing + spring pre-sowing measures, WD – pre-winter disc harrowing + spring pre-sowing measures. Cover crops: R – spring rye (*Secale cereale*), V – vetch (*Vicia sativa*), ns – not significant.

reduced tillage and CT. In the analyzed experiment in all terms of testing and all tillage treatments, the arable layer of soil contained significantly higher amount of organic matter (SOM) than the subsoil layer. In the 0-20 cm layer the SOM content was higher under the conservation tillage with the use of rye than with CT, while in the subsoil layer under the conventional tillage more SOM was stated than in the conservation tillage. Many authors have observed that the tendency for SOM under NT is to concentrate near the surface, while in CT systems SOM is more uniformly distributed (Castro Filho *et al.*, 2002; Franzluebbers, 2002; Madari *et al.* 2005; Zibilske *et al.*, 2002). Pinheiro *et al.* (2004) found that total organic carbon concentration was greater under no-tillage (19 g kg^{-1}) than under conventional tillage (11 g kg^{-1}) at a depth of 0-5 cm, but not significantly different (average 13 g kg^{-1}) at a depth of 5-10 cm. No-till resulted in 58% greater soil organic C concentration in the top 4 cm of soil than in the top 4 cm of the plow-till treatment (Zibilske *et al.*, 2002).

The results from this three-year study show that the average proportion of soil aggregates with diameter of 0.25-10 mm in the arable layer of soil (0-20 cm), depending on the period of studies in the seasons of onion vegetation ranged from 47.9%, in the spring before the start of the tillage, to 49.2% during the onion harvest. The proportion of macroaggregates in the 20-40 cm soil layer was on average in the range of 46.0% after winter and before the beginning of spring tillage, to 51.8% at crop maturity (Table 2).

The favourable influence of inter-crop plants on the aggregation status of soil in the 0-20 cm layer was visible at all sampling dates, but it was most evident after winter and the beginning of onion vegetation. The role of plant biomass in improving soil structure indicators has been shown by many authors (Hermawan and Bomke, 1997; Dąbek-Szreniawska *et al.*, 2002; Mulumba and Lal, 2008; Zimny 1999; Yang *et al.,* 2007). The study of Barral *et al.* (2007) showed a clear deterioration in the structure as a consequence of tillage, which was considered to be a consequence of lower SOM content. Franzluebbers (2002) found that soil under long-term NT contained a greater proportion of macroaggregates (> 0.25 mm) than under long-term CT. Compared with CT, NT promotes macroaggregation (Madari *et al.*, 2005). Also, in our studies, the greatest increase in the proportion of soil aggregates of 0.25-10mm was noted on the plots with no tillage (NT) and direct sowing of onion into mulch from after-crop cover plants. After winter the contribution of aggregates in this fraction in the arable layer of soil covered with plant mulch was on average 50.3% and in the bare soils with conventional tillage (CT) 43.4%. Similar dependence was also noted in the initial period of onion vegetation (3-4 leaf stage), and in the time of harvest, although with the passage of time, these differences decreased. Under the influence of various methods of mixing of mulching cover plants with soil (SD or WD) also observed were the increase of percentage participation of soil macroaggregates (∅ 0.25-10mm), but this influence was lower than that of the plant matter forming mulch without mixing with soil (NT). Similar results were achieved by Hermawan and Bomke (1997). Increased content of soil aggregates with diameter of >0.5 mm after introducing into the soil chopped straw was noted by Acton *et al.* (1963) and the maximum effect was achieved after one week of incubation, which was referred to the highest content of microorganism exudates noted in soil in that period.

Mulching cover plants had a similar effect on soil aggregation, even though the biomass of spring vetch insensibly increased the share of aggregates with diameter of 0.25-10 mm in the 0-20 cm layer of soil (on average 49.3%) in comparison with rye (48.5%). Favourable influence of spring vetch and Tansy Phacelia mulch was confirmed by many studies (Błażewicz-Woźniak *et al.*, 2001; Sato *et al.*, 2007; Sisti *et al.*, 2004; Wyland *et al.,* 1996; Zimny, 1999). According to Hermawan and Bomke (1997), the mulch from fall rye had better influence on soil structure than mulch from spring wheat. Smith *et al.* (1958) found that the influence of plant residues on improvement of soil structure depended on the cellulose fraction contained in them. Ding *et al.* (2006) noted differences in the chemical composition of humus depending on the type of cover plants, but in all cases the use of biomass of inter-crop plants increased the organic matter content in 0-25 cm layer of soil in comparison with conventional tillage.

In the analyzed experiment, the proportion of microaggregates with diameters of <0.25 mm in the arable soil layer was significantly higher (8.3%) than in subsoil (20-40 cm), which was 6.0% (Table 3). The smallest proportion of microaggregates (<0.25 mm) was observed after the winter before spring soil tillage. Quantity of smallest fractions increased gradually after the start of the vegetation period, especially in the arable layer, reaching a maximum at crop maturity (9.2%). Rye as a cover plant protected better the soil from pulverization than vetch. Protective effect of plant mulch compared to conventional tillage (CT) was most evident in the period after wintering. Weill *et al.* (1988) noted lower soil fragmentation into microaggregates <0.25 mm in the presence of yearly amendment of farmyard manure (FYM) (40 t ha^{-1}) than under NPK fertilization and in case of direct sowing (NT) as compared to plough tillage (CT). Cambardella and Elliott (1993) also noted positive influence of NT in comparison with CT on the dispersive properties of soil. Plough tillage favoured in particular the fragmentation of soil into fractions with diameters <0.053 and 0.053-0.25 mm, limiting the share of aggregates of fraction >0.25 mm in the fragmented soil. Also, in the studies of Błażewicz-Woźniak (2002) conventional tillage (CT) caused an increase of soil pulverization in comparison with no tillage (NT). The CT system showed significantly higher numbers of aggregates in the smaller diameter classes (<0.25, 0.25 and 0.50 mm) than NT (Castro Filho *et al.*, 2002). Lenart (2004)

Table 3. Influence of tillage and cover crops on the formation of aggregate with diameters >10 mm and < 0.25 mm in the soil layers 0-20 and 20-40 cm (mean for 2004 - 2006)

Treatment		Aggregates > 10 mm					Aggregates < 0.25 mm				
		After winter	Beginning of vegetation	Full of vegetation	At harvest	Mean	After winter	Beginning of vegetation	Full of vegetation	At harvest	Mean
						0-20 cm					
CT		49.1	48.6	42.4	47.7	47.0	7.5	8.8	9.1	8.3	8.4
NT+R		43.6	39.8	41.7	39.0	41.0	6.7	8.1	8.8	7.2	7.7
SD+R		43.3	42.7	44.4	48.9	44.8	6.6	7.9	8.1	7.4	7.5
WD+R		48.8	47.9	39.9	42.1	44.7	7.7	7.5	10.2	9.4	8.7
Mean (R)		45.2	43.5	42.0	43.3	43.5	7.0	7.8	9.0	8.0	8.0
NT+V		42.1	38.2	39.8	32.2	38.1	7.0	9.4	8.7	10.5	8.9
SD+V		43.2	43.5	44.8	47.5	44.8	7.1	9.1	9.5	9.4	8.8
WD+V		44.7	43.8	38.1	41.1	41.9	7.5	8.1	10.1	7.8	8.4
Mean (V)		43.3	41.8	40.9	40.3	41.6	7.2	8.9	9.4	9.2	8.7
Mean		45.0	43.5	41.6	42.6	43.2	7.2	8.4	9.2	8.6	8.3
						20-40 cm					
CT		44.2	35.5	40.2	50.4	42.6	7.0	7.5	7.5	5.8	7.0
NT+R		49.5	48.2	44.1	43.3	46.3	4.2	4.0	5.2	8.2	5.4
SD+R		53.8	50.9	43.5	50.5	49.7	3.8	4.6	5.5	4.8	4.7
WD+R		46.9	43.9	37.7	44.4	43.2	6.7	6.2	7.3	6.4	6.7
Mean (R)		50.1	47.7	41.8	46.1	46.4	4.9	4.9	6.0	6.5	5.6
NT+V		48.0	41.8	45.0	34.6	42.4	4.1	8.2	6.8	10.1	7.3
SD+V		52.2	32.9	39.5	43.7	42.1	4.6	9.3	5.9	5.9	6.4
WD+V		46.7	52.4	44.3	48.7	48.0	6.1	3.8	4.8	3.7	4.6
Mean (V)		49.0	42.4	42.9	42.3	44.2	4.9	7.1	5.8	6.6	6.1
Mean		48.8	43.7	42.0	45.1	44.9	5.2	6.2	6.1	6.4	6.0
LSD 0.05 for:	treatments					5.7					1.8
	depth					ns					0.6
	dates					3.7					1.1

Explanation as in Table 2.

also noted positive influence of no-tillage in comparison with plough tillage as well as FYM incorporation on the microstructure of soil which could be seen in decrease of soil fragmentation into smallest fractions with diameter of < 0.05 mm with simultaneous increase of contribution of aggregates with diameter of >0.05 mm in this soil.

The proportion of clods formed with diameters >10 mm in soil was high (Table 3). In the arable layer of soil 0-20 cm there were fewer clods formed (43.2%) than in the subsoil layer (44.9%) but the differences were not statistically significant. In the studied terms the share of this fraction was reverse in comparison with the silt formations. Significantly more clods were found in soil after winter (on average 46.9%), and the fewest at crop maturity (41.8%). At that time, the pulverization of soil was the highest (Table 4). In the arable layer of soil the clod formations with diameter of > 10 mm ranged from 45% (after the winter, but before the beginning of spring field works) to 42.6% in the fall time. Dąbek-Szreniawska (2004) explains the seasonal character of the changes of soil aggregate stability with the activity of soil microorganisms. The optimum climatic conditions for exudate production by microorganisms occur in spring and summer. This is reflected in the improvement of aggregation and structure of soil, while the other seasons favour their decomposition. The aggregate stability increased with decreasing diameter (Hevia *et al*., 2007). The large aggregates show low resistance to mechanic stresses and low resistance to water as compared to microaggregates (Walczak and Witkowska, 1976).

Spring rye and spring vetch, as mulching plants, decreased the proportion of clods produced in the arable layer by 4.8%, on average, in comparison with conventional tillage (CT) without mulching plants (Table 3). This illustrates the protective character of plant mulch. Soil covered with plant mulch did not undergo compaction or crust formation, as did bare soil (Nyakatawa *et al*., 2001).

According to Hevia *et al.* (2007) lower aggregation of CT in relation to NT and VT (vertical tillage) is consequence of lower organic matter contents. A high correlation between aggregate stability and SOM has been reported by Chaney and Swift (1984). Many authors have shown that physical disturbance of soil structure has resulted in decreasing aggregate stability paralleled by a loss of SOM (Beare *et al.*, 1994; Six *et al.*, 2000), indicating a link between SOM and soil aggregate dynamics (Pinheiro *et al.*, 2004).

T a b l e 4. Correlation between SOM and share of soil aggregate fractions

Share of soil aggregates (mm)	Depth (cm)	
	0-20	20-40
0.25-10	-0.0505	-0.1695
< 0.25	- 0.0930	-0.0889
> 10	0.0053	0.1741

In the analyzed experiment no significant correlation was noted between the content of SOM and the proportions of soil aggregate fractions (Table 4). This can be explained by small differences in the SOM content in the soil in studied treatments.

CONCLUSIONS

1. Conservation tillage increased the soil organic matter content after 3 years in comparison with conventional tillage. Spring rye increased SOM content more than spring vetch.

2. Spring rye and spring vetch cultivated as cover plants positively influenced the soil aggregation, expressed by the lower cloddiness and pulverization of soil in comparison with conventional tillage (CT) without plant mulches.

3. Leaving the cover plant mulch on the soil surface (NT) increased the proportion of soil macroaggregates with ∅ 0.25-10 mm as well as decreased the proportion of fractions of < 0.25 mm and > 10 mm in comparison with the treatments of pre-winter tillage (WD) and spring pre-sowing (SD).

4. Changes in soil aggregation under the influence of cover mulching plants and simplifications of the overall tillage system for onion was noted mainly in the arable layer (0-20 cm).

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