Int. Agrophysics, 2004, 18, 311-315

INTERNATIONAL
**Agrophysics**
www.ipan.lublin.pl/int-agrophysics

# Effect of management practices on soil organic matter, microbial biomass and aggregate stability of Orthic Luvisol

*M. Dąbek-Szreniawska*[1]*, *J. Kuś*[2], *and E. Balashov*[3]

[1]Institute of Agrophysics, Polish Academy of Science s, Doświadczalna 4, P.O. Box 201, 20-290 Lublin 27, Poland
[2]Institute of Soil Science and Plant Cultivation, Królewska 1, 24-100 Puławy, Poland
[3]Agrophysical Research Institute, 14 Grazhdansky Prospekt, St. Petersburg, 195220 Russia

*Received May 10, 2004; accepted July 13, 2004*

A b s t r a c t. Because of the importance of soil organic matter (SOM) and wet aggregate stability (WAS) on soil quality, the maintenance of satisfactory levels of these parameters is an integral component of soil management strategy. Our studies were undertaken to assess the effects of organic and monoculture management practices on the relationships of SOM and its labile forms with WAS in a loamy-sandy Orthic Luvisol. The organic management practice (OP) included only manure compost incorporation before potato was planted in a crop rotation with spring barley, red clover for 2 years, and winter wheat. The monoculture management practice (MP) consisted of amendments with mineral fertilizers with continuous winter wheat. Our data showed that OP, as compared to MP, contributed to a greater accumulation of SOM and microbial biomass carbon (MBC) in water-stable aggregates. There were marked management-induced differences in WAS and the distribution of some water-stable aggregate-size fractions. The results of our studies also showed that OP resulted in a higher efficiency of soil microorganisms in utilizing available organic carbon for the formation of new biomass than MP.

K e y w o r d s: management practice, organic matter, microbial biomass, aggregation

## INTRODUCTION

Soil structure, one of the basic elements of soil fertility, is constantly affected by the action of various mechanical, physicochemical and biological factors, and therefore can undergo remarkable changes. The formation of water-stable and durable soil aggregates is a complex process. The number and quality of the aggregates is influenced by many factors *eg* fertilization, plant vegetation, action of atmospheric factors during the seasons of the year, and the action of microorganisms as well as higher organisms existing in soil (Dąbek-Szreniawska 1977a; b; c; Dąbek-Szreniawska *et al*., 2000). Microbial polysaccharides are one of the most effective organic agents that promote soil aggregate stability, but the effectiveness of these polymers in stabilizing soil particles varies between microbial strains and the prevailing environmental conditions (Martens and Frankenberger, 1992).

Labile forms of soil organic matter (SOM), as compared to its total content, are often more informative in estimating the self-regeneration of soil structure and more sensitive to the effects of cultivation practices (Aoyama *et al*., 1999; Franzluebbers and Arshad, 1997). Therefore, microbial biomass carbon (MBC), particulate organic matter (POM) and wet aggregate stability (WAS), also referred to as the total amount of water-stable aggregates, have often been studied to evaluate the cultivation-induced changes in soil quality (Anderson and Domsch, 1978; Cambardella and Elliott, 1992; Chan and Heenan, 1999; Neufeldt *et al*., 1999). Measurements of MBC combined with SOM (MBC/SOM ratio), basal respiration (metabolic quotient, $qCO_2$) and WAS have also been used as sensitive indicators of organic matter state, soil stress, productivity and degradation (Anderson and Domsch, 1989; 1990; Plante and McGill, 2002). Such information is useful for the selection of reliable management practices to achieve satisfactory levels of SOM and WAS.

The objectives of the present studies were to: 1) evaluate the effects of organic and monoculture management practices on SOM and its labile forms in a loamy sand, Orthic Luvisol, and 2) estimate the possible changes in WAS as related to the SOM and MBC content in the soil.

*Corresponding author's e-mail: mdsz@demeter.ipan.lublin.pl

## MATERIALS AND METHODS

Disturbed field moist soil samples were collected in May 2000 from the 0-20 cm layers of agricultural plots situated at the Experimental Station of the Institute of Soil Science and Plant Cultivation (IUNG) in Puławy, Poland. The experimental plots were located on a light brown loamy-sandy soil classified as Orthic Luvisol according to the FAO classification.

The organic management practice (OP) included manure compost incorporation at a rate of 33 t ha$^{-1}$ applied in 1996 before potato was planted in a crop rotation with spring barley, red clover for 2 years, and winter wheat. Content of organic matter, total N, available P and K in the manure compost was equal to 93.1 g C kg$^{-1}$ , 4.5 g N kg$^{-1}$, 1.4 g P kg$^{-1}$ and 3.3 g K kg$^{-1}$ dry matter. In these experiments all the soil samples were taken only from OP plot with winter wheat after red clover as the proceeding crop. The monoculture management practice (MP) consisted of amendments with mineral fertilizers (120 kg N, 80 kg $P_2O_5$ and 100 kg $K_2O$ ha$^{-1}$ yr$^{-1}$) with continuous winter wheat.

Water-stable aggregates were collected by sieving air-dried aggregates through a set of 0.25, 0.43, 1, 3, 5 and 6.3 mm sieves in water for 1 min (40-50 stroke length, 10 cycles min$^{-1}$). SOM content of the total soil samples and of different size fractions of water-stable aggregates was determined using the wet combustion method. To measure the basal respiration (BR) and substrate-induced respiration (with a rate of glucose of 5 mg g$^{-1}$ soil), 4 g of air-dried total soil samples and water-stable aggregates moistened to 60% of saturation were incubated in glass jars (40 cm$^3$) for 24 h at 30°C and afterwards for 3 h at 22°C, respectively. The $CO_2$ production was measured with a gas chromatograph and calculations of MBC were made according to Anderson and Domsch (1978). All the measurements of soil properties were made in three replicates. Coefficients of correlation between soil properties were calculated using 95% confidence limit. Significance of differences between treatments was determined by analysis of variance (one-way ANOVA). All statistical analyses were performed using the STATISTICA 5.0 package (StatSoft Inc., USA).

## RESULTS AND DISCUSSION

The OP as compared to the MP contributed to a greater accumulation of SOM in the whole soil samples and all the size fractions of water-stable aggregates (Fig. 1).

The observed SOM sequestration could possibly be explained by stabilization of organic substances by two mechanisms: association of SOM with clay particles and occlusion of organic substances in pores of micro- and macro-aggregates (Golchin *et al.*, 1995). The clay particles are known to contribute markedly to the stabilization of SOM by its association with Ca-, Al- or COOH-groups bound to the charged surfaces of clay minerals (Parfitt *et al.*, 1999).

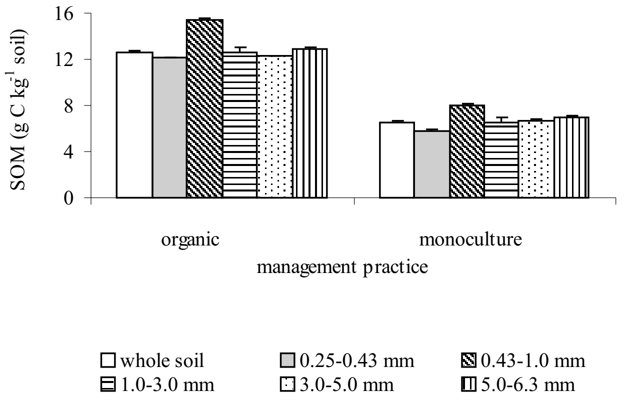


**Fig. 1.** SOM content in the total samples and water-stable aggregates of different size fractions of Orthic Luvisol at OP and MP (Error bars are standard deviations at P < 0.05, n = 3).

The highest SOM content was observed in the 0.43-1 mm fraction of water-stable aggregates at both management practices. However, there were no significant differences in SOM content in the 0.25-0.43, 1-3, 3-5 and 5-6.3 mm fractions of water-stable aggregates at the applied management practices. Neither of the practices led to a higher accumulation of SOM in the above-mentioned fractions of aggregates, compared to that in the whole soil. Small differences in SOM content in the total soil and water-stable aggregates may be explained by its: 1) weak stabilization by the above-mentioned mechanisms and 2) weak physico-chemical protection against mineralization by micro-organisms in separate aggregate-size fractions.

Despite the small management-induced differences in SOM content, we observed a pronounced distribution of water-stable aggregate-size fractions in OP and MP plots (Fig. 2).

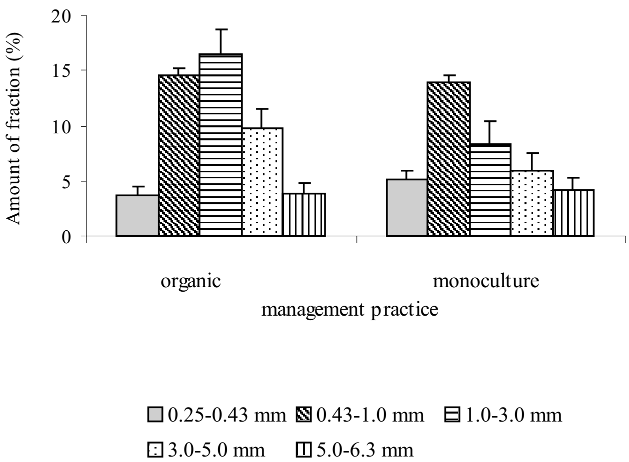


**Fig. 2.** Distribution of water-stable aggregate-size fractions in Orthic Luvisol at OP and MP (Error bars are standard deviations at P < 0.05, n = 3).

The amount of 0.43-1 mm aggregate-size fraction (in MP and OP plots) and that of 1-3 mm aggregate-size fraction (in OP plot) were significantly higher than the amounts of other fractions. However, only the amount of 0.43-1 mm fraction responded additively to SOM accumulation at both management practices. The observed differences in distribution of water-stable aggregate-size fractions could be probably induced more by differences in the quality (POM, MBC ) of SOM than by changes in its total amount (Plante and McGill, 2002). Our results mean that SOM content can be an insensitive indicator of changes in structural soil properties. Growing of red clover for two years before winter wheat could result in a high accumulation of carbohydrates and other hydrophobic substances which cause an increase in repellency of soil macro- and microaggregates (Monreal *et al*., 1993).

In general, the total amount of water-stable aggregates was significantly higher in the OP plots (48%) than in the MP plots (37%).

Our data showed that OP, as compared with MP, resulted in significantly higher values of BR (0.25 vs 0.18 mg $CO_2$-C kg$^{-1}$ soil h$^{-1}$) in the total soil. This means a higher availability of organic matter for soil microorganisms in the OP plot than in MP. Additionally, the MBC content was significantly higher in the OP plot than the MP plot (Fig. 3).

At both management practices there was a higher MBC accumulation in aggregates than in the total soil. Our results also demonstrated the formation of more favourable conditions for the sequestration of labile forms of SOM in the OP plot which was enriched with higher amount of available organic substances than the MP plot.

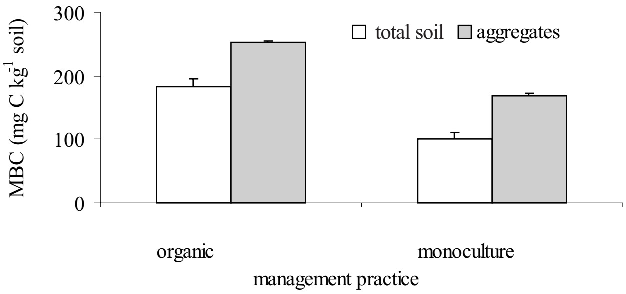


**Fig. 3.** MBC content in the whole samples and water-stable aggregates of Orthic Luvisol at OP and MP (Error bars are standard deviations at P < 0.05, n = 3).

Metabolic quotient ($qCO_2$, a ratio of BR to MBC content) shows the efficiency of microbial community in utilizing available organic compounds for the formation of new biomass (Anderson and Domsch, 1990). Our results demonstrated that soil microorganisms utilized available organic carbon more effectively in the OP plot (1.37 g $CO_2$-C mg$^{-1}$ MBC h$^{-1}$) than in the MP plot (1.78 g $CO_2$-C mg$^{-1}$ MBC h$^{-1}$). Therefore, we observed higher MBC accumulation in soil with OP than with MP.

Because of the impact of soil degradation there is a need to develop criteria for the evaluation of changes in soil quality. The following physical and chemical attributes can serve as indicators of changes in soil quality under particular agroclimatic conditions: water-holding capacity, bulk density, hydraulic conductivity, aggregate stability, organic matter, nutrient availability/retention capacity, ph, electrical conductivity and exchangable cations (Arshad and Coen 1992; Sokołowska *et al*., 1998; 1999a; b; Hajnos *et al*., 1998; Dąbek-Szreniawska *et al*., 1996; 1999; 2000). MBC/SOM ratios are regarded as sensitive indicators of quality and equilibrium state of organic substances in soils, which corresponds to values of MBC/SOM ratios of 2.3 to 4% (Anderson and Domsch, 1989). Values of MBC/SOM ratios in the whole soil from either the OP or the MP plots showed that SOM did not achieve its equilibrium state in May of 2000 (Fig. 4).

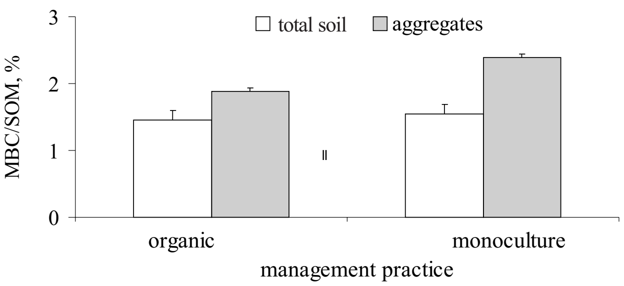


**Fig. 4.** MBC/SOM ratio in the total samples and water-stable aggregates of Orthic Luvisol at OP and MP (Error bars are standard deviations at P < 0.05, n = 3).

A low input of the manure- or plant residue-derived organic matter, its insufficient physico-chemical protection and unfavourable previous weather conditions could likely result in the non-equilibrium state of organic substances in the OP and MP plots. We observed an increase in the MBC/SOM ratios in water-stable aggregates, which surprisingly corresponded to the equilibrium state of SOM in the MP plot. However, the higher portion of MBC in SOM in water-stable aggregates of the MP plot did not contribute to increasing their total amount.

Results of statistical analysis showed that WAS was strongly correlated to SOM and MBC content (Table 1). The data also demonstrated strong negative relationships of MBC content and WAS with $qCO_2$. This could mean that the stabilization of water-stable aggregates was induced by the efficiency of soil microbial community in utilizing available organic carbon for the formation of new biomass. Nevertheless, analysis of variance showed that differences in SOM content between the OP and MP plots had significant effects on WAS values (P < 0.001). The SOM

**T a b l e 1.** Coefficients of correlation (r) of properties of Orthic Luvisol

| Parameter | SOM | BR | MBC | $qCO_2$ | MBC/ SOM |
|---|---|---|---|---|---|
| SOM | | | | | |
| BR | 0.83* | | | | |
| MBC | 0.97* | 0.93* | | | |
| $qCO_2$ | -0.92* | -0.58 | -0.84* | | |
| MBC/SOM | -0.35 | 0.19 | -0.13 | 0.56 | |
| WAS | 0.99* | 0.79 | 0.96* | -0.93* | -0.35* |

*indicates significant coefficients of correlation at $P < 0.05$, $n = 6$.

content was also a significant factor for variances in $qCO_2$ values ($P < 0.001$) and MBC content ($P = 0.003$) between the OP and MP plots.

As it is known, microorganisms are an important factor active in soil biochemical processes and biology plays a major role in the stabilization of soil structure (Oades 1993). The main stimulus for the examination of soil polysaccharides of both bacterial and plant origin was introduced by repeated reports concerning their effect on the soil structure (Harris *et al*., 1966; Dąbek-Szreniawska, 1974; 1977a; b; c; Martin, 1971; Lynch and Bragg, 1985). The slime substances produced by soil microorganisms are mainly polysaccharides and are formed as a result of decomposition of organic residues contained in soil. The interest in understanding the relationship between physical properties and polysaccharide content in soil was intensified by reports which pointed out that slimes produced by soil microorganisms might bind soil particles into stable aggregates.

The research on the relation between fertilization, cultivation system and water stability of soil aggregates and the number of microorganisms showed that the number of bacteria and fungi and water stability of aggregates were higher in the organically fertilized soil (Dąbek-Szreniawska *et al*., 2000). Dąbek-Szreniawska (1974; 1977a; b; c) studied the influence of the bacterial biomass of *Arthrobacler* sp. on the formation and water stability of aggregates in the soil with the addition of plant fragments, mineral fertilizers (NPK, Ca) and bentonite. The highest increase in the water stability of aggregates occurred under the influence of bacterial biomass with simultaneous addition of plant residues. Bentonite generally increased the durability of aggregates. The mineral fertilizers, NPK, caused a decrease in the water stability of aggregates formed by adding bacterial biomass. The process of soil aggregate formation is not only affected by specific micro-organisms but by their association as well. The equilibrium between synthesis and decomposition of aggregate-binding substances is connected with environment conditions and the content of nutritive substances which affect microbiological activity.

Reganold *et al*. (1987) showed that organically-farmed soil had significantly higher organic matter content, thicker topsoil depth, higher polysaccharide content, lower modulus of rupture and less soil erosion than conventionally-farmed soil.

## CONCLUSIONS

1. It was found that OP, as compared to MP, resulted in greater accumulation of SOM and MBC as well as in higher total amount of water-stable aggregates and some of the aggregate-size fractions in the loamy-sandy Orthic Luvisol.

2. The distribution of aggregate-size fractions was weakly induced by changes in SOM content for both the OP and the MP plots.

3. SOM did not achieve an equilibrium in May of 2000 at both management practices even despite the favourable conditions for microbial transformation of organic substances in the OP plot.

## REFERENCES

**Anderson J.P.E. and Domsch K.H., 1978.** A physiological method for the quantitative measurement of microbial biomass in soils. Soil Biol. Biochem., 10, 215-221.

**Anderson T.-H. and Domsch K.H., 1989.** Ratios of microbial carbon to total organic carbon in arable soils. Soil Biol. Biochem., 21, 471-479.

**Anderson T.-H. and Domsch K.H., 1990.** Application of eco-physiological quotients ($qCO_2$ and qD) on microbial biomasses from soils of different cropping histories. Soil Biol. Biochem., 22, 251-255.

**Aoyama M., Angers D.A., N'Dayegamiye A., and Bisson-Nette N., 1999.** Protected organic matter in water-stable aggregates as affected by mineral fertilizers and manure applications. Can. J. Soil Sci., 79, 419-425.

**Arshad M.A. and Coen G.M., 1992.** Characterization of soil quality: Physical and chemical criteria. Am. J. Altern. Agric., 7, 25-32.

**Cambardella C.A. and Elliott E.T., 1992.** Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J., 56, 777-783.

**Chan K.Y. and Heenan D.P., 1999.** Microbial-induced soil aggregate stability under different crop rotations. Biol. Fertil. Soils, 30, 29-32.

**Dąbek-Szreniawska M., 1974.** The influence of *Arthrobacter* sp. on the water stability of soil aggregates. Polish J. Soil Sci., 7, 169-179.

**Dąbek-Szreniawska M., 1977a.** The role of selected bacteria in the formation of water-stable soil aggregates independently of other microorganisms. Zesz. Probl. Post. Nauk Roln., 197, 339-354.

**Dąbek-Szreniawska M., 1977b.** The influence of *Arthrobacter* sp. on soil aggregation. Zesz. Probl. Post. Nauk Roln., 197, 319-328.

**Dąbek-Szreniawska M., 1977c.** The influence of some chemical substances on the water stability of soil aggregates formed by adding bacterial slimes. Zesz. Probl. Post. Nauk Roln., 197, 329-336.

**Dąbek-Szreniawska M., Księżopolska A., and Kuś J., 1999.** Number of microorganisms and electrolitical conductivity of soil under various systems of cultivation. Acta Agrophysica, 23, 31-38.

**Dąbek-Szreniawska M., Wyczółkowski A.I., Jończyk K., and Kuś J., 2000.** Relation between fertilization, cultivation system and water stability of soil aggregates and number of microorganisms. Acta Agrophysica, 38, 47-57.

**Dąbek-Szreniawska M., Wyczółkowski A., Józefaciuk B., Księżopolska A., Szymona J., and Stawiński J., 1996.** Relations between soil structure, number of selected groups of soil microorganisms, organic matter content and cultivation system. Int. Agrophysics, 10, 31-35.

**Franzluebbers A.J. and Arshad M.A., 1997.** Soil microbial biomass and mineralizable carbon of water-stable aggregates. Soil Sci. Soc. Am. J., 61, 1090-1097.

**Golchin A., Oades J.M., Skjemstad J.O., and Clarke P., 1995.** Structural and dynamical properties of soil organic matter as reflected by 13C natural abundance, pyrolysis mass spectroscopy and solid-state 13C NMR spectroscopy in density fractions of an oxisol under forest and pasture. Austr. J. Soil Res., 33, 59-76.

**Hajnos M., Sokołowska Z., Dąbek-Szreniawska M., and Kuś J., 1998.** Influence of cultivation system (ecological and conventional) on porosity of podzolic soil. Polish J. Soil Sci., 31, 33-41.

**Harris R.F., Chesters G., and Allen O.N., 1966.** Dynamics of soil aggregation. Advances in Agronomy, 18, 107-169.

**Lynch J.M. and Bragg E., 1985.** Microorganisms and soil aggregate stability. Advances in Soil Science, 2, 133-171.

**Martens D.A. and Frankenberger W.T., 1992.** Decomposition of bacterial polymers in soil and their influence on soil structure. Biol. Fertil. Soils, 13, 65-73.

**Martin J.P., 1971.** Decomposition and binding action of polysaccharides in soil. Soil Sci. Biol. Biochem., 3, 33-41.

**Monreal C.M., Schnitzer M., and Campbell C.A., 1993.** Influence of organic structures on aggregate stability. Can. J. Soil Sci., 73, 649-650.

**Neufeldt H., Ayarza M., Resck D., and Zech W., 1999.** Distribution of water-stable aggregates and aggregating agents in Cerrado Oxisols. Geoderma, 93, 85-99.

**Oades J.M., 1993.** The role of biology in the formation, stabilization and degradation of soil structure. Geoderma, 56, 377-400.

**Parfitt R.C., Yuan G., and Theng B.K.G., 1999.** A 13C NMR study of the interactions of soil organic matter with aluminium and allophane in podzols. European J. Soil Sci., 50, 695-700.

**Plante A.F. and McGill W.B., 2002.** Intraseasonal soil macroaggregate dynamics in two contrasing field soils using labeled tracer spheres. Soil Sci. Soc. Am. J., 66, 1285-1295.

**Reganold J. P., Elliott L.F., and Unger Y.L., 1987.** Long-term effects of organic and conventional farming on soil erosion. Nature, 330, 370-372.

**Sokołowska Z., Hajnos M., Bowanko G., and Dąbek-Szreniawska M., 1999a.** Physicochemical properties of the grey-brown podzolic soil under red clover cropping. Acta Agrophysica, 23, 155-165.

**Sokołowska Z., Hajnos M., Bowanko G., Dąbek-Szreniawska M., and Wyczółkowski A., 1998.** Changes in selected physicochemical properties of soil under ecological and conventional cultivation. Zesz. Probl. Post. Nauk Roln., 460, 351-360.

**Sokołowska Z., Hajnos M., and Dąbek-Szreniawska M., 1999b.** Relation between adsorption of water vapor, specific surface area and kind of the cultivation system. Polish J. Soil Sci., 32, 3-12.