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Microbial activity and particulate organic matter content in soils with different tillage system use*

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A b s t r a c t. The main objective of the studies was to determine the changes of microbiological activity and content of the labile fraction of organic matter (POM) in soils under reduced tillage and no-tillage systems, as compared to the conventional tillage. At a private farm in Rogów the content of microbial biomass C was about 13 and 8% higher in soil under no-tillage and reduced tillage, respectively, than in soil managed in the conventional manner. Similar trends in microbial biomass C content were noticed in the soil sampled from the fields in Żelisławki. Microbial respiration, measured under laboratory conditions as the intensity of CO_2 evolution, was higher in soils under no-tillage than under conventional tillage in Rogów and Żelisławki, at up to 30 and 22% (on average), respectively. The highest values of the activity of dehydrogenases were obtained also in soils under no-tillage system at both experimental sites. The microbial quotient (microbial biomass C/C_{org} ratio) showed the highest values in no-tillage soils, but the metabolic quotient qCO_2 in conventionally managed soils at both experimental sites. The increase of POM fraction expressed as a percentage of total OM was higher by about 34% in Rogów soil under no-tillage, as compared to the soil under conventional tillage. Also, in Żelisławki, a higher increase of POM in total organic matter content was observed in soil under conservation tillage systems (reduced and no-tillage) than under conventional tillage, by about 10-15%.

K e y w o r d s: tillage, microbial biomass C, soil dehydrogenase activity, particulate organic matter

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INTRODUCTION

Simplifications in soil management are applied on a wide scale, especially in USA and in many countries of Western Europe. A simplified management protects soil against the negative effects caused by conventional treatment, such as high rate of organic matter decomposition, intensive evolution of carbon dioxide, low stability of soil aggregates, nutrients leaching and runoff. Preliminary analyses of Polish soil-climatic conditions, potential risk of soil erosion and customarily applied crop rotation systems showed an increased interest in simplified management systems in Poland lately. The ability to estimate organic matter fractions quantitatively in both conventional and simplified soil management practices is especially important for understanding soil organic matter dynamics. The microbial biomass C is one of the most important indicators of ongoing changes in soil organic matter. Published results show that microbial biomass C comprises 1-5% of total C_{org} (Anderson and Domsh, 1989; Gajda, 2008; Gajda and Martyniuk, 2005; Sparling, 1992). Soil quality does not depend just on the physical and chemical properties of the soil, but it is very closely related to its biological properties as well. The estimations of CO_2 evolution indicated that about 95% of total CO_2 evolved from soil was of microbial origin, which confirmed an extremely important role of microorganisms in soil metabolism (Masto *et al*., 2006). Considering the above findings, numerous authors who discuss problems of soil quality *eg* Doran and Parkin (1996), Marriott *et al*. (2006), Tan *et al*. (2007), indicate the possibility of use of organic matter quality and quantity and biomass of microorganisms and their activity (respiration rate, enzymatic activity) as indicators of soil quality and productivity. It has also been observed that the labile fraction of soil organic matter showed high sensitivity to changes in soil environment caused by the management system applied (Cambardella and Elliott, 1992; Lal, 2002; Liebig *et al*., 2004; Marriott and Wander, 2006; Wander and Yang, 2000). For example, particulate organic matter represents a pool of organic materials that is intermediate in the decay continuum between organic residues and well-decomposed humic substances. Published data indicate that POM is a very dynamic fraction of organic matter and an important source of C in soil (Cambardella and Elliott, 1992; Cambardella *et al*., 2001; Denef *et al*., 2007; Gajda e*t al*., 2001; Galantini and Rosell, 2006), therefore, during the last decade the idea of using labile fraction of organic matter (POM) as an indicator of soil quality was accepted by many researchers in USA and around the world.

The aim of the investigations was to determine the effect of reduced tillage and no-tillage systems on changes of chosen parameters of biological activity and particulate organic matter content in two different soils, in comparison to the changes resulting from conventional tillage use.

MATERIALS AND METHODS

The studies were based on field experiments conducted in the years 2003-2007. The experimental fields were located in two regions of Poland differing in soil and climatic conditions: at a private farm in Rogów (Zamość region, E Poland) and an experimental station in Żelisławki (Gdańsk region, N Poland). The private farm in Rogów is located on a silt soil (>40% silt and clay fraction) and the experimental station in Żelisławki on a silty loam soil (>30% of silt and clay fraction). Some properties of the soils are presented in Table 1. Crops in this experiment were grown in different soil tillage systems – conventional tillage (CT), reduced tillage (RT) and no-tillage (NT) on non-replicated experimental fields of about 1 ha each. In the applied crop rotation system the following plants were grown: in Rogów – winter wheat, peas, and winter wheat with intercrop; in Żelisławki – spring barley, winter wheat, and sugar beet. Soil samples were taken in a random manner twice a year from the in-row planting area at a depth of 0-15 and 15-30 cm across each trial. The internal diameter of the probe tip was 29 mm. A representative sample of soil taken from the experimental fields weighed about 2000 g for each depth. Immediately following field sampling, samples were placed in double plastic bags and stored at 4°C for analyses completed within two weeks. Soil samples from each site and depth were first weighed, then thoroughly mixed, and 13 to 15 g subsamples were dried at 105°C for 24 h to determine soil water content. Composite soil samples were sieved through a 2 mm mesh sieve in field moist condition before using them for biologically sensitive analyses. The fresh homogenized soil samples were analyzed as follows:

- microbial biomass C content using fumigation-incubation (F-I) method originally described by Jenkinson and Powlson (1976a, b) with modifications of Gajda and Martyniuk (2005b). Microbial biomass C was calculated from the difference between CO_2 evolved from fumigated soil in a vacuum desiccator for 18-24 h at 25°C in vapours of ethanol-free chloroform and unfumigated soil in 0-10 days of incubation, and divided by conversion factor Kc = 0.45 (fraction of biomass C mineralized to CO_2);
- rate of CO_2 evolution from soil was measured using the titration method only in control soil samples which were treated the same way as samples for microbial biomass C content, except for the fumigation procedure, and calculated from cumulative CO_2-C evolved from control soil in 10 days of incubation;
- activity of dehydrogenases according to the Casida *et al*. (1964) method.

All analyses of chosen parameters of soil microbiological activity were performed in three replicates for each representative soil sample.

For better characterization of the soil environment, two ecophysiological parameters – the microbial quotient (the microbial biomass C-to-C_{org} ratio) and the metabolic quotient (qCO_2) (the basic respiration to microbial biomass C ratio) were calculated as well. For C_{org}, total N and POM analyses air dried soil was used. Carbon and nitrogen

T a b l e 1. Some physical and chemical properties of soils under conventional (CT), reduced (RT) and no-tillage (NT) management systems

Site	Granulometric composition (%, dia in mm)			Tillage	pH_{H_2O}	EC ($dS\ m^{-1}$)	C_{org}	N_{total}	C:N
	1.0-0.1	0.1-0.02	<0.02						
Rogów	4	54	42	CT	6.2	1.16	0.88	0.06	14.7
				RT	6.7	1.42	0.90	0.06	14.9
				NT	6.8	1.19	0.81	0.06	13.5
Żelisławki	36	35	31	CT	6.2	1.28	1.05	0.07	15.0
				RT	6.4	0.89	0.81	0.06	13.5
				NT	6.5	1.23	0.74	0.06	12.3

concentrations were determined once a year using the Dumas method – FP-528-LECO. The quantity of POM was measured using the Cambardella *et al*. (2001) modified method in which POM was estimated according to the loss-on-ignition (LOI) procedure as detailed by Schulte and Hopkins (1996). The modified method for POM estimation was published by Gajda *et al*. (2001).

Data were statistically analysed using the ANOVA method. Differences at $P<0.05$ were considered as significant.

RESULTS AND DISCUSSION

The measurement of microbial biomass C is used to evaluate soil quality (Gil-Sotres *et al*., 2005; Spedding *et al*., 2004). During the five-year study the highest measurements of microbial biomass C were obtained in soil under NT taken from Rogów. As compared to soils managed conventionally, the measured contents of microbial biomass C in soils under NT and RT were higher by about 13 and 8%, respectively. A significant increase of microbial biomass C pool (about 2-fold) was noticed in NT soil in Rogów in 2007 as compared to microbial biomass C measurements obtained in 2003 (Fig. 1A). Similar trends in microbial biomass C content were also observed in soil taken from the experimental fields in Żelisławki. The highest content of microbial biomass C was measured in soil under NT system. As compared to the RT and CT soil, the microbial biomass C content in NT soil was higher by about 11 and 21%, respectively. Also, a significant increase of microbial biomass C pool (about 2-fold) was noticed in Żelisławki in NT soil in 2007, as compared to the quantity of microbial biomass C estimated in 2003 (Fig. 1B). The higher measurements of microbial biomass C content in soils under conservation tillage systems demonstrate that less soil disturbance favoured larger microbial populations and activities in comparison to conventional soil disturbed by repeated tilling. Similar results were reported by Calderon *et al*. (2002), Doran *et al*. (1998) and Flieβbach and Mäder (2000). Liebig *et al*. (2004), Lalande *et al*. (2005) and Marinari *et al*. (2006) observed that lower microbial biomass C content in soils under conventional tillage was often due to reduced C_{org} in those soils.

Soil microbial biomass, the living and most dynamic component of soil organic matter, may also indicate potential biological activity of soil (Doran and Parkin, 1996). For example, this activity is reflected by soil respiration measured in this study by CO_2 evolution. As it was indicated by *eg* Doran and Parkin (1996) and Masto *et al.* (2006), soil respiration gives an estimate of microbial decomposition activities and the carbon cycling in the soil. In this study, considerable differences in CO_2 concentrations were found among the studied management systems. Similarly to microbial biomass C contents, in all experimental years the highest rate of soil respiration was detected in the NT soil taken from Rogów (Fig. 2). The amounts of CO_2 evolved from Rogów NT soil averaged 30 and 18% higher as compared to CT and RT soil, respectively (Fig. 2A). Also, in Żelisławki the amounts of CO_2 evolved from NT soil were significantly higher, by about 22 and 8% on average, as compared to CT and RT, respectively (Fig. 2B). Differences between management systems in soil expressed by microbial biomass C contents and CO_2 evolution were statistically

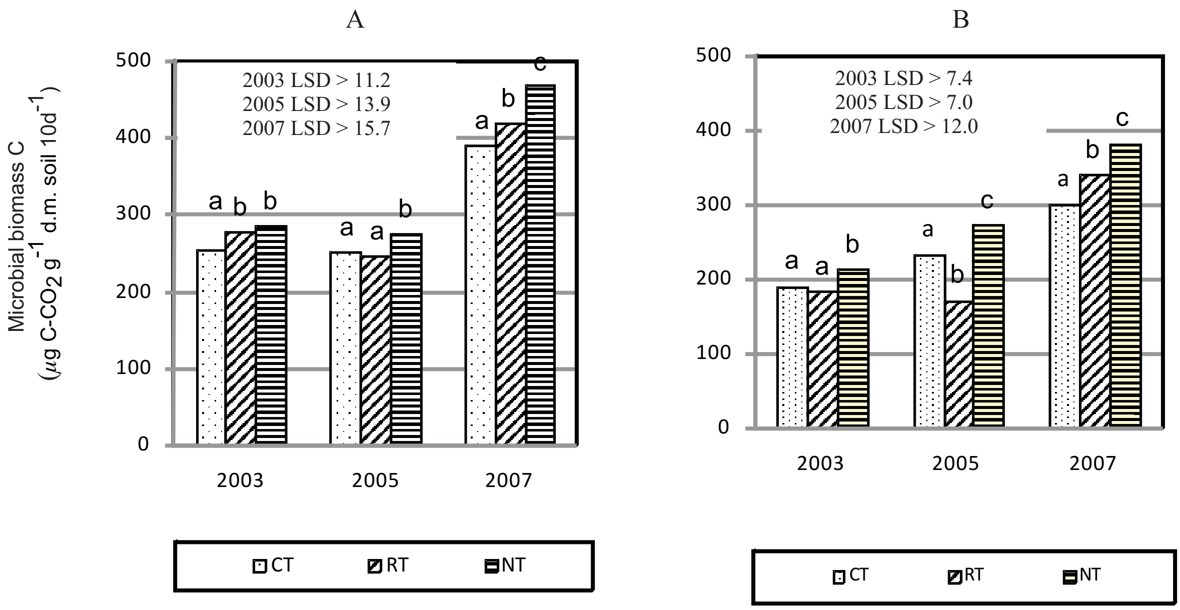
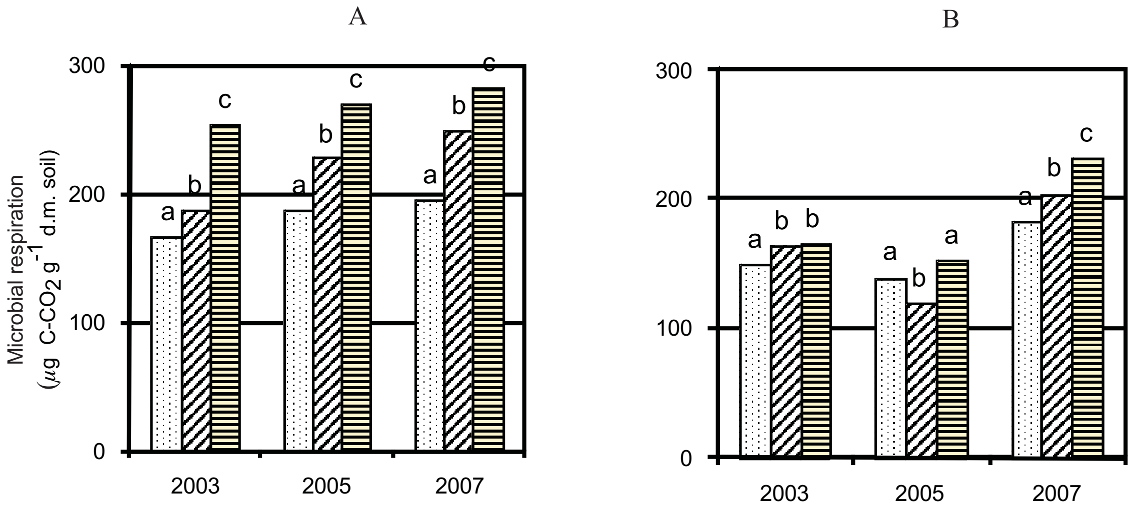
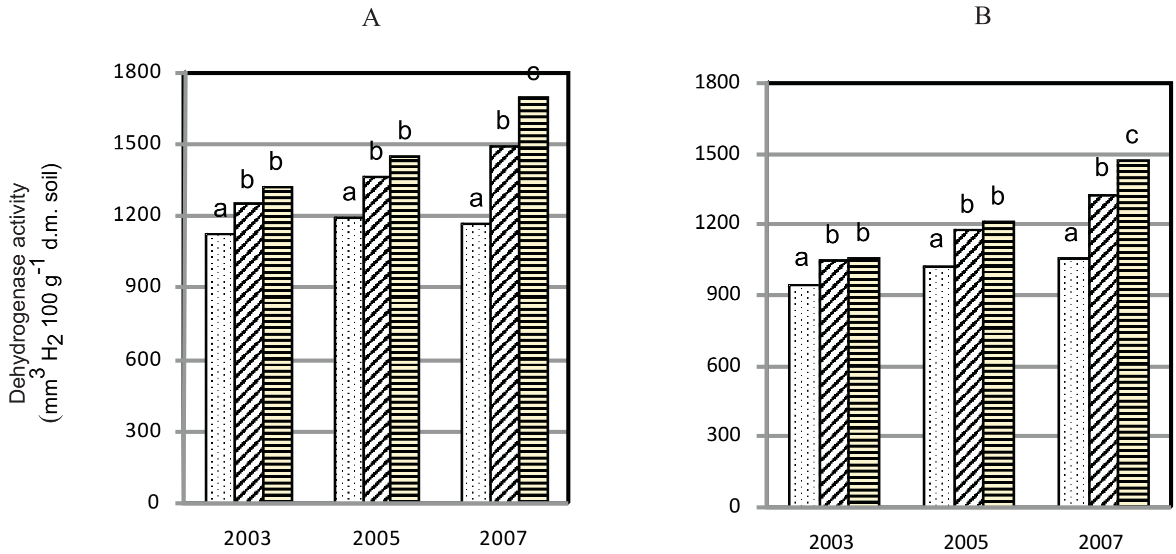


Fig. 1. Comparison of microbial biomass C content in Rogów (A) and Żelisławki (B) soils under conventional (CT), reduced (RT) and no-tillage (NT) management systems in 2003-2007; a, b, c – values marked with different letters are statistically significant at P>95.0%, LSD – the lowest statistical difference.



2003 LSD > 10.1; 2005 LSD > 2.3; 2007 LSD > 8.5   2003 LSD > 1.3; 2005 LSD > 2.0; 2007 LSD > 5.0

Fig. 2. Comparison of the rate of CO_2 evolution from Rogów (A) and Żelisławki (B) soils. Explanations as in Fig. 1.



2003 LSD > 22.6; 2005 LSD > 49.8; 2007 LSD > 49.6   2003 LSD > 52.0; 2005 LSD > 18.2; 2007 LSD > 29.4

Fig. 3. Comparison of the activity of dehydrogenase system in Rogów (A) and Żelisławki (B) soils. Explanations as in Fig. 1.

significant at 95% confidence level (P ≥ 95.0) (Figs 1 and 2). These results are consistent with observations reported by Balota *et al.* (2003), Calderon *et al.* (2000), Doran *et al.* (1998), and Flieβbach and Mäder (2000) who suggest that the lack of major disturbance in soil, such as tilling, provides a steady source of C_{org} which supports higher microbial populations and its activity.

Changes in biological activity and fertility of soil in response to various soil management practices can also be determined using the activity of soil enzymes *eg* the activity of the dehydrogenase system (Doran and Parkin, 1996; Martyniuk *et al*., 2001; Gajda and Martyniuk, 2005; Gajda, 2008). In our studies, the effect of applied soil tillage system on the activity of dehydrogenases in soil was quite noticeable, regardless of the season and climatic conditions (Fig. 3). At the private farm in Rogów, the activity of the dehydrogenase system was higher in NT soil by about 1.3 times, on average, as compared to the CT soil (Fig. 3a). Similar trends in the activity of dehydrogenases were observed in soil sampled on the experimental fields in Żelisławki. In comparison to the CT soil, the measurements of the activity of dehydrogenases in NT soil were higher by about 1.3 times, also (Fig. 3B). Statistical analyses confirmed that the applied management systems differentiated the activity of dehydrogenases in soil significantly at the 95% confidence level (P≥95.0) (Fig. 3). Previous research has shown that soil microbial biomass and enzyme activity respond more quickly to management practices than the soil chemical properties do (*eg* organic matter) thus should be considered as sensitive indicators of soil quality (Bergstrom *et al.,* 1998; Beyer *et al*., 1999; Marinari *et al*., 2006).

The effect of soil depth on the studied parameters of biological activity was also observed. In general, the activity of the dehydrogenase system and microbial biomass C content differed most significantly (up to 60 and 50% on average, respectively) in the surface (0-15 cm) and subsurface (15-30 cm) layers of soils under applied tillage systems at both experimental sites (Fig. 4). Probably, the results reflected a lower number of microorganisms and associated activity in the subsurface layers than in the surface layers of both studied soils. Similar results were published by Angers *et al*. (1999) and Gajda (2008).

The microbial quotient (proportion of total soil C_{org} present as microbial biomass C) can be an indicator of the changes undergone by the organic matter of the soil (Masto *et al*., 2006). In this field trial the ratio of microbial biomass C/total C_{org} was higher in soil under NT system (5.75 and 5.16 at Rogów and Żelisławki, respectively) than in soil under CT (4.43 and 2.86, at Rogów and Żelisławki, respectively). The larger pool of microbial biomass C in NT soil indicates that no-tillage system creates more beneficial conditions in soil environment for the development (proliferation) and activity of soil microorganisms (Table 2). Similar results were published by Böhme *et al*. (2005), Dilly (2005) and Gajda (2008). Sparling (1992) suggests that a higher ratio of microbial biomass C/total C_{org} indicates also that more active organic matter is present and that soil OM is more susceptible to changes.

The metabolic quotient (qCO_2) (basic respiration divided by microbial biomass C) has been proposed over the past decades as an indicator of ecosystem disturbance and development (Dilly, 2006; Böhme *et al*., 2005). Also, it serves as an indicator of the physiological status of soil microorganisms. Differences in qCO_2 are often discussed as a reaction to stress or different community structure. In our studies, in 2007 the qCO_2 reached lower values under conservation tillage systems at both experimental sites (RT – 0.48 and NT – 0.46 at Rogów, and RT – 0,52 and NT - 0.50 at Żelisławki) as compared to CT in Rogów and Żelisławki soils – 0.60 and 0.61, respectively (Table 2). Previous studies of Böhme *et al*. (2005) have also suggested that values of qCO_2 are greater in disturbed conditions. It indicates that the repeated tillage was the most regularly disturbed treatment and no-tillage treatment was the least disturbed, especially as the experiment progressed. Similar results have also been published by Wardle *et al*. (1999), Marinari *et al*. (2006) and Gajda (2008).

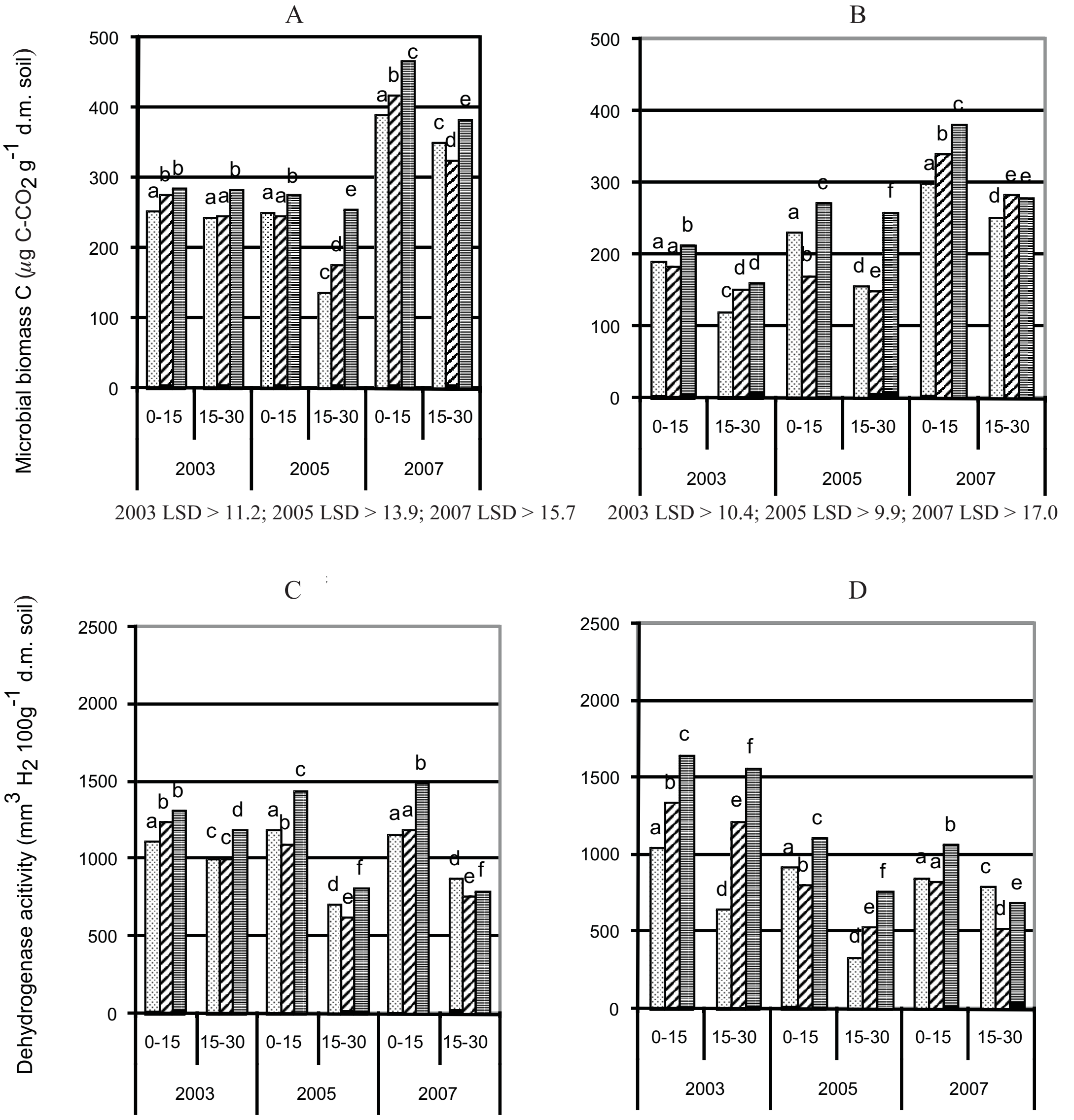
During the five-year research the obtained results of studied parameters of biological activity were more variable for soils under CT system as compared to soils under NT and RT tillage systems at both experimental sites.

Applied management system significantly affects the content of POM fraction (diameter of POM aggregates 0.053-0.5 mm) in soil (Denef *et al*., 2007; Flieβbach and Mäder, 2000; Liebig *et al*., 2004; Tan *et al*., 2007). In this study, at both experimental sites (Rogów and Żelisławki) significantly higher contents of POM were obtained in soils under conservation tillage systems (RT and NT) than in CT, by about 26% on average (Fig. 5). Besides, the conducted observations indicated a significant decrease of POM fraction in conventionally tilled soil. The concentrations of POM measured in 2007 in CT soils in Rogów and Żelisławki decreased markedly as compared to POM concentrations measured in 2003, by about 2 and 7%, respectively. Although, in both soils under RT and NT system, where large amounts of rich plant residues are incorporated every year into the soil, the increase of quantity of POM ranged from 16 to 27% higher in 2007, respectively, as compared to the data obtained in 2003 (Fig. 6). In the presented research the amount of crop residues, particularly those of roots, remaining in the soils after the harvests were not measured. However, based on relatively similar crop yields harvested on these soils *eg* 5.4-8.5 t ha^{-1} (on average) of winter wheat grain in 2003-2007, it could be assumed that the soils received comparable amounts of organic residues each year.

Also, several authors reported rapid depletion of the labile fraction of OM in soil as a result of cultivation practices, and rapid increase when soil was not disturbed by tilling (Marriott and Wander, 2006; Sleutel *et al*., 2006; Wander and Yang, 2000).

Moreover, it is interesting to point out that the increase of POM fraction, expressed as the percentage of total soil OM, was the highest in NT soil in Rogów, in 2007, and averaged about 34% higher than the measurement made in 2003. Also, in Żelisławki in 2007 the observed increase of POM fraction in total OM was higher in RT and NT soils than in CT soil by about 10-15%, on average, as compared to the measurements made in 2003 (Fig. 7). Statistical analyses showed significant differences between the effect of the applied tillage system on the content of POM fraction in studied soils at the 95% confidence level (P≥95.0). Albrecht *et al*. (2000) and Tan *et al*. (2007) have also observed a significant increase of the percentage of POM fraction in the total OM contained in RT soil.

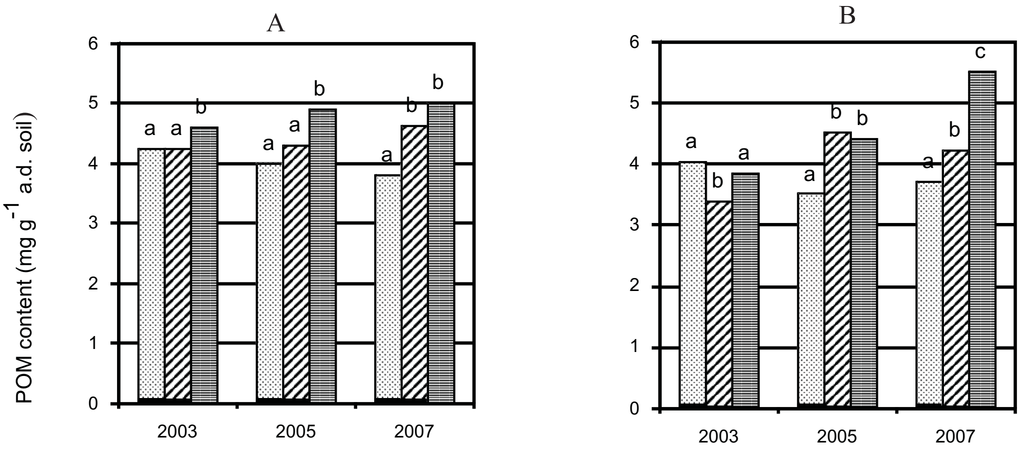
An effect of soil depth on the quantity of POM fraction was also observed. The measured contents of POM in the 0-15 cm layer were greater by about 15-30% than in subsurface soil - 15-30 cm layer, especially in the NT and RT soil (Fig. 8). The measurements of POM distribution within the arable layer (0-30 cm) made for Rogów soil showed that the POM content was even higher in the deeper layers (below 15 cm depth) than in the surface layer in soil under CT (by 15% on average) as an effect of the plough use. In the soil under RT a significant decrease of POM content simultaneously with soil depth increase was observed (Fig. 9). Similar results were obtained



2003 LSD > 11.2; 2005 LSD > 13.9; 2007 LSD > 15.7 2003 LSD > 10.4; 2005 LSD > 9.9; 2007 LSD > 17.0

2003 LSD > 22.6; 2005 LSD > 49.7; 2007 LSD > 48.7 2003 LSD > 73.6; 2005 LSD > 25.7; 2007 LSD > 41.6

Fig. 4. Effect of soil depth (0-15 and 15-30 cm) on microbial biomass C content and dehydrogenase activity in Rogów (A, C) and Żelisławki (B, D) soils. Explanations as in Fig. 1.



2003 LSD > 0.20; 2005 LSD > 0.20; 207 LSD > 0.20 2003 LSD > 0.10; 2005 LSD >0.21; 2007 LSD > 0.27

Fig. 5. Comparison of the quantity of POM in Rogów (A) and Żelisławki (B) soils. Explanations as in Fig. 1.

T a b l e 2. Microbiological characteristics of soils under conventional (CT), reduced (RT) and no-tillage (NT) management systems

Site	2003		2005		2007	
	CT	RT	NT	CT	RT	NT
	Microbial biomass C (MBC) (μg C-CO_2 g^{-1} d.m. soil)					
Rogów	253	276	285	390	418	466
Żelisławki	190	183	213	300	341	382
	Microbial quotient MBC soil C_{org} (%)					
Rogów	2.86	3.07	3.52	4.43	4.64	5.75
Żelisławki	1.81	2.26	2.88	2.86	4.21	5.16
	Metabolic quotient C resp. MBC (q CO_2) (μg C-CO_2 μg^{-1} MBC)					
Rogów	0.65	0.70	0.60	0.60	0.48	0.46
Żelisławki	0.80	0.80	0.70	0.61	0.52	0.50

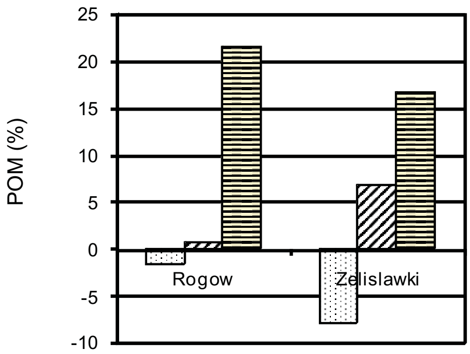


Fig. 6. Increase and/or decrease of POM quantity in soils estimated in 2007 in relation to 2003. Explanations as in Fig. 1.

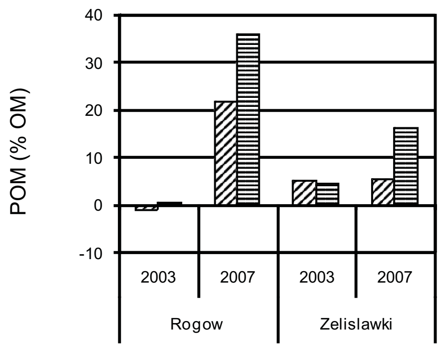


Fig. 7. Increase of POM expressed as % of total OM content in soils under reduced tillage RT and no-tillage NT systems in relation to soils under conventional tillage CT system in 2003 and 2007. Explanations as in Fig. 1.

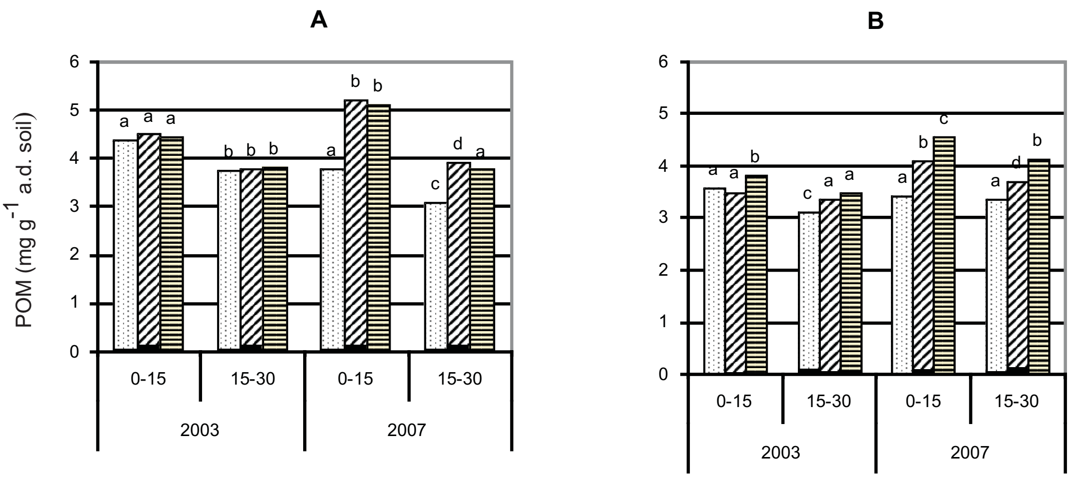


Fig. 8. Effect of soil depth (0-15 and 15-30 cm) on POM content in Rogów (A) and Żelisławki (B) soils. Explanations as in Fig. 1.

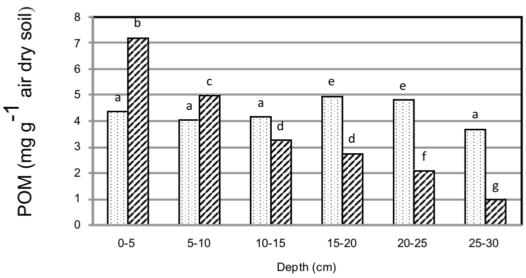


Fig. 9. Distribution of POM fraction in 0-30 cm layer of Rogów soil under winter wheat in conventional CT and reduced RT tillage system. Explanations as in Fig. 1.

by Albrecht *et al*. (2000). They also noticed that tillage created an even distribution of POM throughout the soil profile, but the decrease of tillage inten- sity increased the POM fraction, especially in the upper soil depths.

CONCLUSIONS

1. Conservation tillage systems (reduced tillage and no-tillage) exerted beneficial effects on the soil environment at both experimental sites differing in soil type (silt soil in Rogów and silty loam soil in Żelisławki).

2. In general, at both experimental sites, soils under reduced tillage and no-tillage showed higher microbial biomass content and associated activity of microorganisms as measured by the rate of CO_2 evolution, dehydrogenase system activity and two ecophysiological parameters – microbial and metabolic quotients, as compared to the conventionally managed soils.

3. Among the three tillage systems studied, no-tillage system caused the most significant increase of labile fractions of organic matter as particulate organic matter and microbial biomass C contents in studied soils at both experimental sites.

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