

## Effect of different tillage systems on some microbiological properties of soils under winter wheat\*

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**A b s t r a c t.** The aim of this research was to determine the effect of applied tillage systems on changes of chosen parameters of soil microbiological activity. Analyses of microbiological properties of soil were performed on soil samples collected from long-term field experiments at a private farm in Rogów (Lublin voivodeship) on silt-loam soil and at the IUNG-PIB Experimental Station in Grabów (Masovian voivodeship) on heavy loamy sand. Winter wheat was grown in conventional (CT) and reduced tillage (RT) systems. Analyses of soil taken from experimental fields included the rate of CO<sub>2</sub> evolution using the titration method; microbial biomass C content using the F-I method; dehydrogenase system activity using TTC as a substrate; microbial biomass N content using the F-E method and the Most Probable Number (MPN) of ammonia- and nitrate-forming bacteria. Applied tillage systems affected significantly the analysed parameters of biological activity of tested soils in both experimental years. In general, at both experimental sites, the numbers of specific groups of soil microorganisms estimated on the quantity of biomass C and N were significantly higher in RT soil than in CT soil (by about 20%, on average) at both depths: 0-15 and 15-30 cm. In 2006 and 2007, the dehydrogenase activity, ammonification and nitrification strength of soil reached the highest values mostly in RT soil at both experimental sites. Calculated higher values of microbial quotient and lower values of metabolic quotient in RT soil indicate that the RT system created a more friendly environment for the growth and activity of soil microorganisms, in comparison with the CT system.

**Key words:** microbial respiration, microbial biomass C and N, activity of dehydrogenases, ammonia- and nitrate-forming bacteria, tillage system

### INTRODUCTION

Management practices can have major impacts on the content of soil organic carbon (SOC) in soil. Davidson and Ackerman (1993) reported 20% to 40% loss of soil organic matter following the conversion of previously untilled soils to agricultural production. Conversion of land from plough tillage to long-term no-tillage management often increases soil organic C and N content (Buyanovsky and Wagner, 1998; Doran, 1980, 1987; Gajda and Martyniuk, 2005; Gajda *et al.*, 2001; McCarty and Meisinger, 1997; McCarty *et al.*, 1995, Marinari *et al.*, 2006).

The increase of global temperature may affect several major soil processes with a consequent impact on soil quality. Quantity and quality of organic matter in soil, together with products of its biological and biochemical transformations, determine whole complex of biological and biochemical properties influencing soil quality and productivity. Soil microorganisms, the living and active component of soil organic matter (SOM), play an extremely important role in creation of soil quality and productivity through their activity in degradation of plant and animal residues, participation in biogeochemical nutrients cycle and soil structure formation, detoxification of agrochemicals and organic pollutants in the soil environment (Anderson and Domsch, 1989; Brooks *et al.*, 2008; Carter *et al.*, 1999; Doran *et al.*, 1998; Franzluebbers, 1999; Jenkinson, 1988; Rice *et al.*, 1994; Sparling, 1992).

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Recent concern about increasing levels of atmospheric CO<sub>2</sub> and consequent global warming has increased interest in the sequestration or storage of C in the form of SOM through the use of conservation management systems in agricultural practice (Lal, 2000; West, 2002).

The objective of this work was to determine the effects of conventional and reduced tillage systems on changes of chosen parameters of microbiological activity of two different soils.

#### MATERIALS AND METHODS

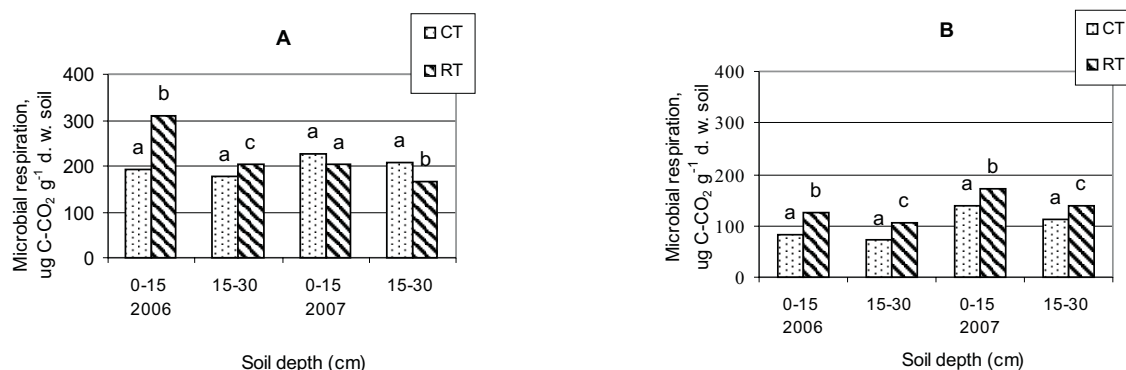
Analyses of microbiological properties of soil were performed on soil samples collected throughout the growing seasons of 2006 and 2007 from the long-term field experiment (started in 2002) at a private farm (PF) in Rogów (Lublin voivodeship) on a silt-loam soil and at the IUNG-PIB Experimental Station (ES) in Grabów (Masovian voivodeship) on a heavy loamy sand. At both experimental sites winter wheat was grown under two tillage systems: conventional tillage (CT) based on the mouldboard plough and traditional soil tillage equipment with the field surface mulched with chopped wheat straw, and reduced tillage (RT) with the surface mulched with chopped wheat straw based on soil crushing-loosening equipment and a rigid-tine cultivator. All samples were collected from between wheel tracks from soil pits which were dug in the field under the different treatments at both locations. The representative samples, each consisting of 1500 g of soil, were taken from the 0-15, 15-30 cm layers of soil. All fresh soil samples were passed through a 2 mm sieve and stored at 4°C in a refrigerator. Microbiological analyses of 64 soil samples (4 soil depths x 2 tillage systems x 2 locations x 2 samplings x 2 years) included: the rate of CO<sub>2</sub> evolution from soil using the titration method; microbial biomass C content using the F-I (fumigation-incubation) method (Jenkinson and Powlson, 1976) modified by Voroney and Paul (1984); dehydrogenase system activity using TTC as a substrate (Casida *et al.*, 1964); microbial biomass N content using the F-E (fumi-

gation-extraction) method (Jenkinson and Powlson, 1976) modified by Keeney and Nelson (1982); the number of ammonia- and nitrate-forming bacteria using the most probable number (MPN) technique according to McCrady (1980). All analyses were performed using fresh soil in 3 replicates of each sample. Statistical analyses were made separately for each experimental year using the ANOVA method and differences at  $P < 0.05$  were considered as significant.

#### RESULTS AND DISCUSSION

In both experimental years, 2006 and 2007, the applied tillage systems affected significantly the analysed parameters of the microbiological activity of the tested soils.

In 2006, the largest amounts of CO<sub>2</sub> evolved were measured with the RT soil sampled at 0-15 cm depth in Rogów – 310 µg CO<sub>2</sub>-C/g d.w. of soil, on average. Evolution of CO<sub>2</sub> at 15-30 cm depth was about 35% less than at 0-15 cm depth (significant at  $P < 0.05$ ) in the RT system, but in the CT the differences between soil depths were not statistically significant (Fig. 1A). In 2007, larger amounts of CO<sub>2</sub> evolved (about 10-20%, on average) were measured with the Rogów CT soil than with the RT soil. At the depths of 0-15 cm and 15-30 cm of CT soil, amounts of CO<sub>2</sub> evolved averaged 226 and 209 µg CO<sub>2</sub>-C/g d.w. of soil, respectively, in comparison with RT – 204 µg CO<sub>2</sub>-C/g d.w. of soil at 0-15 cm depth and 165.5 µg CO<sub>2</sub>-C/g d.w. of soil at 15-30 cm depth, on average (Fig. 1A). In the second year of the experiment, the differences in CO<sub>2</sub> evolution between soil depths of CT soil were not statistically significant. Similar trends in CO<sub>2</sub> evolution to the ones reported for the Rogów soil in 2006 were observed in both experimental years in soil taken from the experimental fields in Grabów, but the values obtained were less than 50% of those obtained in the Rogów soil (Fig. 1B). Also Dilly (2001), Doran and Parkin (1996) and Marinari *et al.* (2006) reported a higher rate of CO<sub>2</sub> evolution in soil under reduced than conventional tillage system.



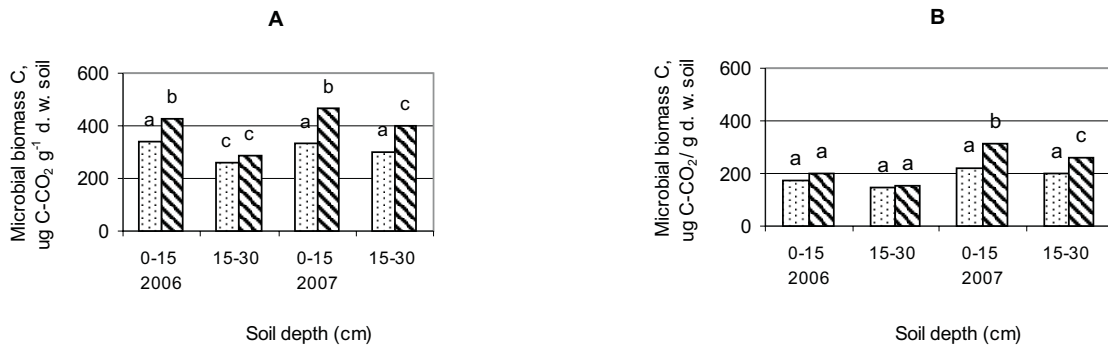
**Fig. 1.** Rate of CO<sub>2</sub> evolution from soils under winter wheat grown in CT and RT systems in Rogów (A) and Grabów (B) in 2006 and 2007. Values marked with the same character are not significantly different at  $P \leq 0.05$

Soil microbial biomass, as the living and most dynamic component of the soil organic matter, may indicate potential for biological activity of soil (Bending *et al.*, 2004; Doran and Parkin, 1994). In both experimental years, 2006 and 2007, the highest content of soil microbial biomass C was estimated in RT soil taken from Rogów at the 0-15 cm depth – 430 and 465  $\mu\text{g CO}_2\text{-C/g d.w.}$  of soil, respectively (on average). Soil managed conventionally contained a smaller amount of microbial biomass C pool (about 20%) than the RT soil. Microbial biomass C contents were smaller at 15-30 cm depth than at 0-15 cm depth in both CT and RT soil, by about 20% and 30%, respectively (significant at  $P < 0.05$ ), as shown in Fig. 2A. Similar trends in microbial biomass C content were observed with soil taken from the experimental fields in Grabów in 2007, but the values obtained in 2006 were less than 50% of those obtained with the Rogów soil. There were no significant differences in soil microbial biomass C content between the two tillage systems in Grabów in 2006 (Fig. 2B). Other authors have also indicated higher results in microbial biomass concentration in soil under reduced tillage, in comparison with the conventional tillage system (Acosta-Martinez *et al.* 2008; Bulluck *et al.* 2002; Doran *et al.*, 1998; Fiebbach *et al.* 2007; Gajda *et al.*, 2001; Liebig and Doran, 1999; Marinari *et al.*, 2006).

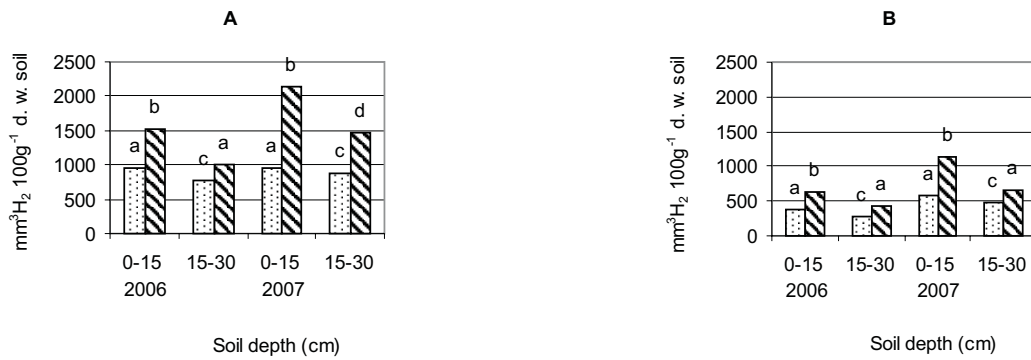
Numerous studies have shown that the activity of soil enzymes can be used as a sensitive indicator of changes in soil biological activity and fertility in response to various soil management practices (Bending *et al.*, 2004; Doran, 1987; Marinari *et al.*, 2006). In our studies, the effect of soil tillage system on enzymatic activity of the soils was determined by assessing the activity of dehydrogenase systems, which provides correlative information on the biological activity and microbial populations in soil as well as indicates the rate of organic matter oxidation (Gajda and Martyniuk, 2005; Gajda *et al.*, 2001; Martyniuk *et al.*, 2001; Włodarczyk, 1998). The activity of the dehydrogenase system in the studied soils was influenced by both the applied tillage systems and soil depth. The greatest activity of dehydrogenases was measured in RT soil in Rogów in the layer of 0-15 cm – 1517.6  $\text{mm}^3 \text{H}_2/100 \text{ g d.w.}$  of soil, and 2131.4  $\text{mm}^3 \text{H}_2/100 \text{ g d.w.}$  of soil, in 2006 and 2007, respectively. Similar trends were observed in the layer of 15-30 cm. In the CT the measurements of dehydrogenases activity were only about 60% (on average) of those measured with the RT soil. In the RT soil, an effect of soil depth (significant at  $P < 0.05$ ) was observed, in both studied years. In the surface layer the measurements of dehydrogenase activity were about 25% (on average) greater than in the subsurface soil in both experimental years (Fig. 3A). The results with the Grabów soil showed similar trends to those obtained with the Rogów soil, but the values in the RT soil in Grabów were only about 35% of those obtained in Rogów (Fig. 3A, B). Similar results have been presented by other authors eg Gajda *et al.* (2000), Marinari *et al.* (2006), Martyniuk *et al.* (2001).

An influence of tillage system on the microbial biomass N content in the studied soils was also observed. The greatest content of microbial biomass N was measured in 2006 in RT soil in Rogów, in both studied layers – 0-15 and 15-30 cm – 33.7 and 28.0  $\mu\text{g N/g d.w.}$  of soil, respectively. In the CT soil the estimations of microbial biomass N were only about 20% (on average) of those measured with the RT soil. In the RT soil, an effect of soil depth (significant at  $P < 0.05$ ) was observed in both experimental years. In the surface layer estimations of microbial biomass N were 20% greater than in the subsurface soil (Fig. 4A). The results with the Grabów soil showed similar trends to those obtained with the Rogów soil, but the values in the RT soil in Grabów were only about 20-40% of those obtained in Rogów (Fig. 4A, B). There were no statistically significant differences in the size of the microbial biomass N pools in the CT soil at both experimental sites in 2006, but in the second year of the experiment, 2007, the differences became deeper and statistically significant at  $P < 0.05$  (Fig. 4A, B). Similar results have been presented by Acosta-Martinez *et al.* (2008), Cookson *et al.* (2008), Doran and Parkin (1996), Gajda and Martyniuk (2005), Mäder *et al.* (1995), Panhurst *et al.* (1998).

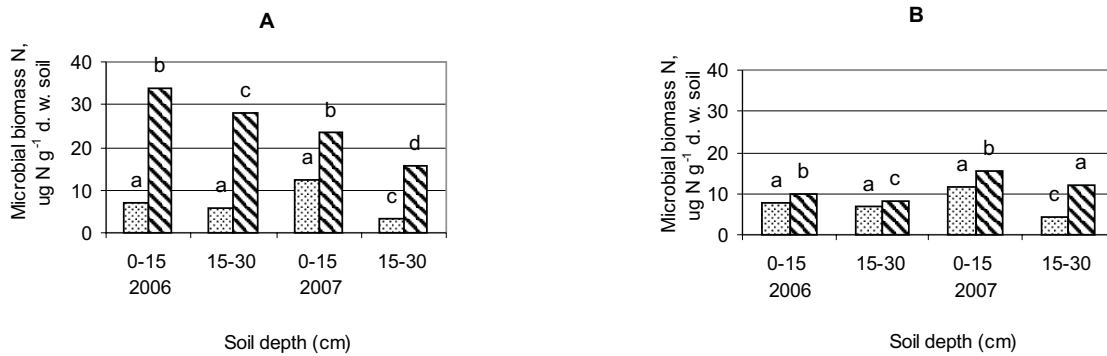
Ammonification is a measure of the net N mineralisation, as immobilisation of  $\text{NH}_4^+$  by soil microorganisms into new biomass occurs simultaneously with the mineralisation process (Winding *et al.*, 2005). Determination of the quantities of soil microorganisms active in decomposition of organic N associations gives the possibility to estimate the ammonification strength of soil. Figs 5A, B and 6A, B show the growth dynamics of ammonia-forming bacteria in soils under winter wheat in 2006 and 2007, respectively, during 7 days of incubation. At the beginning (1-2 days of incubation), the number of ammonia-forming bacteria was very low, especially in experimental year 2006. Differentiation of ammonification strength (significant at  $P < 0.05$ ) affected by tillage system and soil depth appeared after 3 days of incubation, but the maximum of differentiation was reached on the 4th day of incubation in both experimental years. In RT soil taken from Rogów in 2006 and 2007, in both soil depths the strength of ammonification was about 3 times greater than the strength of ammonification measured in CT soil (Figs 5A, 6A). Similar results were obtained in soil taken from the experimental fields in Grabów. In the RT soil in 2006 the measurements of the ammonification strength were about 2 times larger in the 0-15 cm depth range and 1.4 times larger in the 15-30 cm depth range, in comparison with the CT soil (Fig. 5B). In 2007, in the RT soil the measurements of the ammonification strength were about 2.5 times larger in the 0-15 cm depth range and about 2 times larger in the 15-30 cm depth range, in comparison with the CT soil (Fig. 6B). Other authors have reported similar results (Bloem and Breure, 2003; Doran, 1987; Doran *et al.*, 1998; Gunapala and Scow, 1998; Nsabimana *et al.*, 2004; Römbke *et al.*, 2002; Schipper and Sparling, 2000).



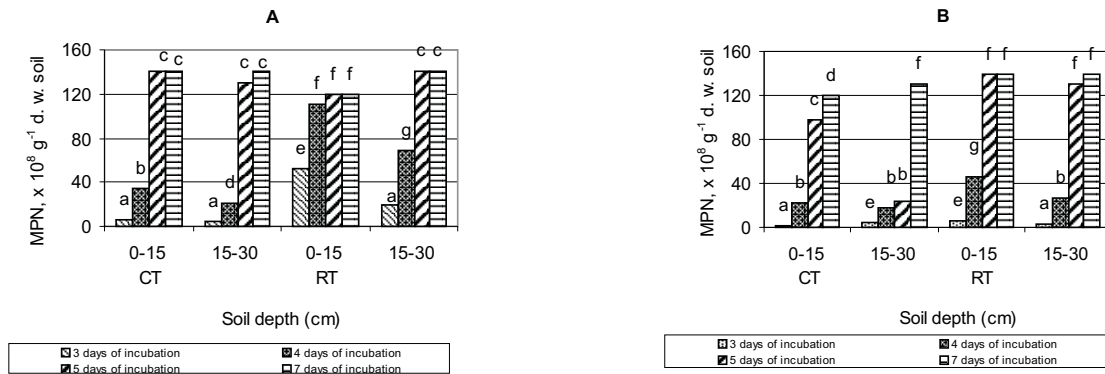
**Fig. 2.** Microbial biomass C content in soils under winter wheat grown in CT and RT tillage systems in Rogów (A) and Grabów (B) in 2006 and 2007.



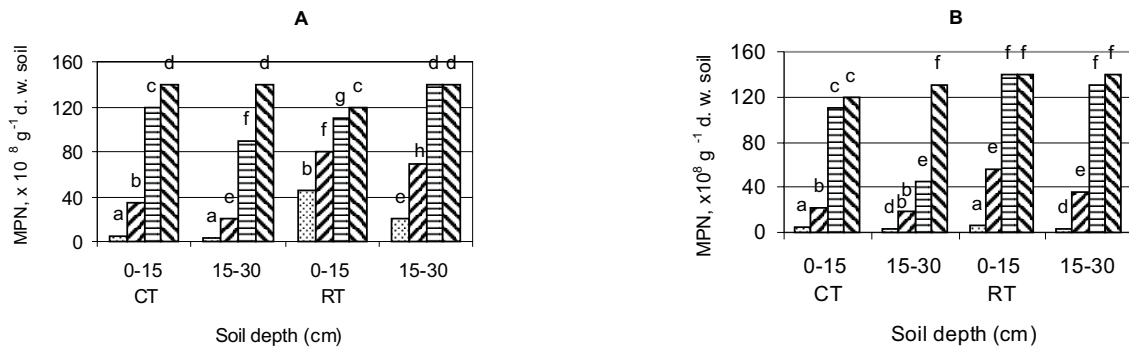
**Fig. 3.** Dehydrogenase system activity in soils under winter wheat grown in CT and RT tillage systems in Rogów (A) and Grabów (B) in 2006 and 2007.



**Fig. 4.** Microbial biomass N content in soils under winter wheat grown in CT and RT tillage systems in Rogów (A) and Grabów (B) in 2006 and 2007.



**Fig. 5.** Most probable number (MPN) of ammonia-forming bacteria in medium inoculated with soils under winter wheat grown in CT and RT in Rogów (A) and in Grabów (B) in 2006.

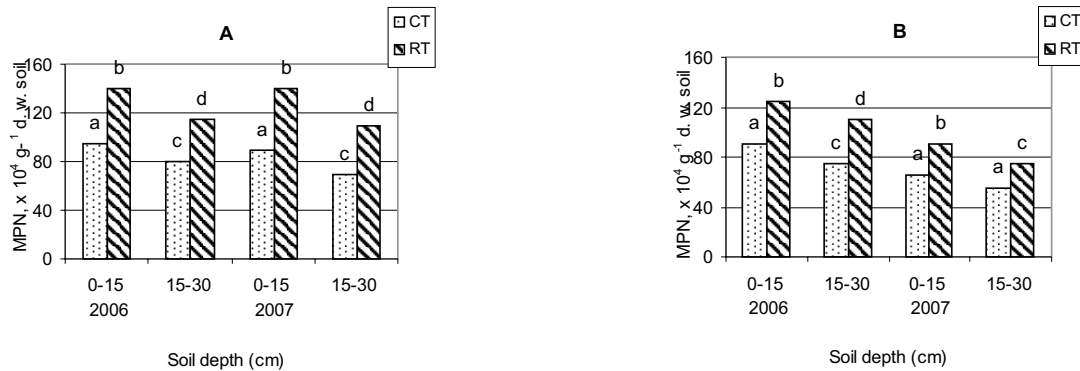


**Fig. 6.** Most probable number (MPN) of ammonia-forming bacteria in medium inoculated with soils under winter wheat grown in CT and RT in Rogów (A) and in Grabów (B) in 2007.

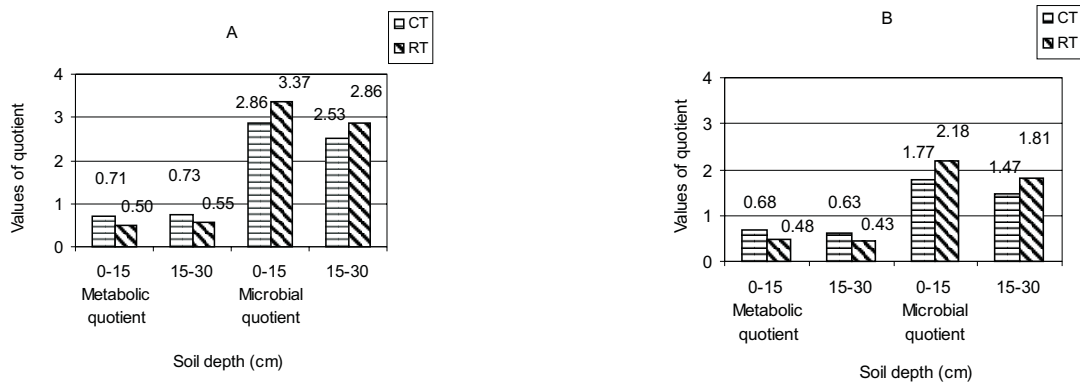
The next step in the degradation of nitrogen compounds in soil is the process of nitrification. Nitrification measurements reflect the population size of the nitrifiers, for which ammonium is an essential substrate. In both experimental years, at both experimental sites, the tillage system and soil depth affected the number of nitrate-forming bacteria (significant at  $P < 0.05$ ). Higher counts of nitrate-forming bacteria (about 1.3 times, on average) were found in the surface layer of reduced- and conventionally-managed soil in Rogów and Grabów, in comparison with the 15-30 cm layer, in both experimental years. The RT soil showed higher counts of nitrate-forming bacteria in both of the studied soil layers (about 1.8 times, on average), in comparison with the CT soil. In general, CT and RT soil taken in Rogów and in Grabów contained similar numbers of nitrate-forming bacteria in both depths ranges. The results show significantly greater nitrification strength of RT soil than soil managed conventionally at both experimental sites in 2006 and 2007 (Fig. 7A, B). Similar results have been published earlier by Winding *et al.* (2005) and Marinari *et al.* (2006).

The metabolic quotient ( $qCO_2$ ), defined as the ratio of basal respiration to microbial biomass, has been proposed over the past decades as an indicator of ecosystem disturbance and development (Anderson and Domsch, 1989; Dilly, 2006). According to Fließbach and Mäder (2000), the metabolic efficiency of a microbial community is supposed to be reflected by its specific respiration rate. Differences in  $qCO_2$  are often discussed as a reaction to stress or different community structure. In our studies, the  $qCO_2$  reached lower values under RT systems in 0-15 cm and 15-30 cm layers (RT – 0.50, 0.55 at Rogów; and RT – 0.48, 0.43 at Grabów) in comparison with CT – 0.71, 0.73 at Rogów; and 0.68, 0.63 at Grabów, respectively (Fig. 8). Previous studies by Insam and Domsch (1989), Stolze *et al.* (2000), Nsabiimana *et al.* (2004), Dilly *et al.* (2005) have also indicated that values of  $qCO_2$  are greater in disturbed conditions. This suggests that the repeated cultivation was the most regularly disturbed treatment and that the reduced treatment was the least disturbed, especially as the experiment progressed.





**Fig. 7.** Most probable number (MPN) of nitrate-forming bacteria (*Nitrosomonas spp.*, *Nitrobacter spp.* i inne) in soils under winter wheat grown in CT and RT in Rogów (A) and Grabów (B) in 2006 and 2007.



**Fig. 8.** Obtained values of microbial quotient and metabolic quotient in soils under winter wheat grown in CT and RT in Rogów (A) and Grabów (B).

The microbial quotient (proportion of microbial biomass C to total soil organic C) can be an indicator of changes undergone by the organic matter of the soil (Angers *et al.*, 1999). In this field trial the ratio of microbial biomass C/total organic C was higher in the surface and subsurface layers of soil under the RT system 3.37, 2.89 at Rogów and 2.18, 1.81 at Grabów than in soil under the CT system 2.86, 2.53 at Rogów and 1.77, 1.47 at Grabów, respectively (Fig. 8). This indicates that a larger pool of microbial biomass C in RT soil creates beneficial conditions in the soil environment for development, proliferation and activity of soil microorganisms. Results obtained previously by Anderson and Domsch (1989), Marinari *et al.* (2006), and Moscatelli *et al.* (2005) showed similar trends.

#### CONCLUSIONS

1. Significant effects of tillage systems on quantities of microorganisms active in C and N transformations were found in the studied soils.

2. In general, in both experimental years, at both experimental sites, the number of populations of soil micro-

organisms estimated on the amount of C and N contained in their biomass was significantly higher in RT soil (about 20-30%, on average) than in CT soil in both depth ranges: 0-15 and 15-30 cm.

3. The dehydrogenases activity, ammonification and nitrification strength of soils reached the highest values mostly in RT soil at both experimental sites.

4. Calculated higher values of microbial quotient and lower values of metabolic quotient in RT soil indicate that the RT system, in comparison with the CT system, was more friendly for the soil environment. It was reflected in increased activity of soil microorganisms – the active pool of the soil organic matter, playing an extremely important role in supplying sources of energy and nutrients in soil necessary for activity of soil biota and growing crops.

5. It was noticed in the 2007 larger measurements that larger amounts of CO<sub>2</sub> were evolved from CT soil than from RT soil in Rogów. This may indicate that repeated tillage results in accelerated oxidation of organic matter by soil organisms, with the untimely release of respired CO<sub>2</sub> back to the atmosphere.

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