Original Research

Microbial Biomass C and N and Activity of Enzymes in Soil under Winter Wheat Grown in Different Crop Management Systems

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Abstract

Microbial and biochemical analyses of soil under winter wheat in a field trial with various cultivation systems (organic, conventional and monoculture) were performed during 3 growing seasons: 2001, 2002 and 2003. The activities of the tested enzymes (dehydrogenase and phosphatases) and microbial biomass C and N contents in the monoculture soil were generally significantly lower than those in the soil from the organic and conventional–short rotation systems, indicating that substantial disturbances may occur in the microbial activity of the monoculture soil.

Keywords: dehydrogenase, phosphatases, soil microbial biomass C and N, farming systems, soil quality

Introduction

Results of our previous studies based on a long-term field experiment indicate that among various microbial parameters, measured activities of dehydrogenase and phosphatases, as well as microbial biomass C and N are often more significantly correlated with chemical characteristics of soils and with crop yields [1, 2, 3]. We also use these parameters to characterize microbial activity of soils, because they are relatively easy to measure by well-elaborated and widely used analytical methods and because they represent important physiological processes of soil microorganisms. These advantages also meet the criteria proposed by Dick et al. [4], Mäder et al. [5], or Pankhurst et al. [6] for microbial parameters to be useful as biomonitors or indicators of disturbances in soil quality and function. The aim of this work was to find out whether changes in soil quality and function caused by different farming systems are reflected by changes in soil microbial activity as characterized by measurements of microbial biomass and activity of enzymes (dehydrogenase and phosphatases).

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Materials and Methods

The studies were based on a long-term field experiment started in 1994 at Osiny Experimental Farm (belonging to Institute of Soil Science and Plant Cultivation - ISSPC) on a grey-brown podzolic soil developed from light clay. Crops in this experiment are grown in different farming systems on non-replicated fields of about 1 ha each. The organic system (OR) consists of 5 fields on which the following crops are rotated: potato - spring barley + intercrop - grass/clover mixture (1st year) - grass/clover mixture (2nd year) - winter wheat. In the conventional-short rotation (C-SR) system with 3 fields winter rape, winter wheat and spring barley are grown and in the conventional-monoculture (C-M) system winter wheat is cultivated every year on the same field. In the OR system 30 t ha^{-1} of grass/clover compost is applied under potato crop and a biological preparation against potato beetle is used. No mineral fertilizers and plant protection chemicals are used in this system. In the two other systems the crops are grown according to the high input recommendations generally used in Poland. In each farming system fields of winter wheat are divided into 4 parts (0.25 ha) on which four cultivars of this crop (Juma, Kobra, Elena and Roma) are grown every year.

For the purpose of these studies, soil samples were collected 3 times during vegetation seasons 2001-2003 from the plough layer (0-20 cm) of soils in the fields under winter wheat cv. Roma. Three composite samples, each consisting of 5 cores (29 mm in diam.) of soil, were taken across the fields. The soil samples were passed through a 2 mm sieve and stored fresh at 4^0C in a refrigerator.

The soil samples were analyzed for microbial biomass C and microbial biomass N contents and respiration rate using the fumigation-incubation method described by Jenkinson [7] and Jenkinson and Powlson [8, 9] in a slight modification as described earlier by Martyniuk et al. [2]. Replicated (3 x 50 g) samples of moist soil (55% WHC) were placed into 100 ml beakers and fumigated in vacuum desiccators for 18-24 h at 25°C in vapours of ethanol-free chloroform. Control samples were treated in the same way, except for fumigation procedure. The fumigated and unfumigated samples were placed into airtight jars 0.9 L volume and incubated for 10 days at 25°C. Microbial biomass C was calculated from the difference between CO_2 evolved from fumigated soil (0-10 days of incubation) and unfumigated soil (10-20 days of incubation) and divided by conversion factor Kc = 0.45 (fraction of biomass C mineralized to CO_2). Soil respiration rate was calculated from the cumulative C-CO_2 evolved from the control soil during 10-20 days of incubation.

The dehydrogenase activity was estimated using TTC (2,3,5-triphenyltetrazolium chloride) as the substrate ac-

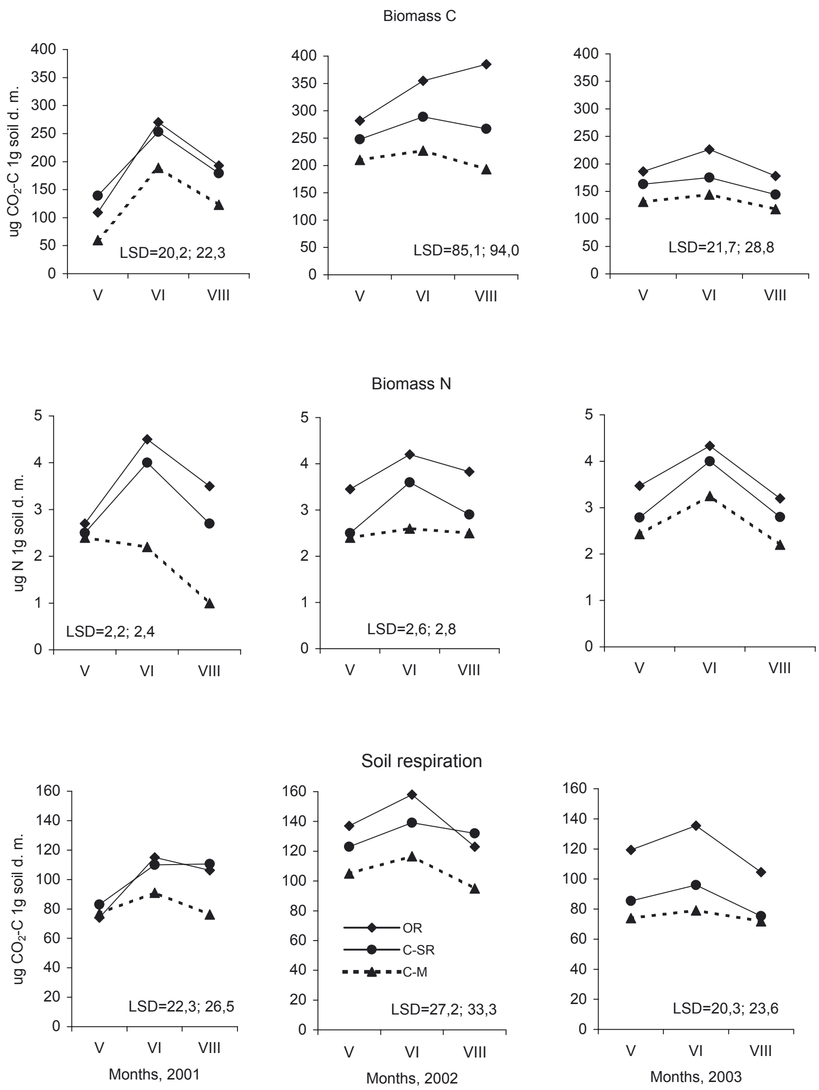

Fig. 1. Microbial biomass C and N content and respiration rate in soil under winter wheat grown in organic (OR), conventional short rotation (C-SR) and conventional monoculture (C-M) farming systems. *LSD ($P<0.05$) numbers indicate significant differences for interactions date/systems and system/dates, respectively.

cording to the Casida et al. method [10], and phosphatases (acid and alkaline) activity using p-nitrophenyl phosphate (PNP) as the substrate according to Tabatabai and Bremner method [11]. Data were statistically analyzed by two-way analysis of variance (ANOVA).

Results and Discussion

Soil microbial and biochemical parameters measured in this work are presented (Figs. 1 and 2) separately for the years 2001, 2002 and 2003, because in the case of OR and C-SR systems in each of these years winter wheat was grown on different fields. Only in the case of the C-M system wheat was cultivated on the same field every year. Basic physical and chemical characteristics of these soils, given in Table 1, indicate that the examined soils were similar with respect to their mechanical structure (contents of <0.02 mm fraction) but differed with respect to soil reaction and organic C contents. Soil pH (in water) ranged from 6.1 in the OR soil (field no. 1) to 7.0 in the C-SR soil from field no. 8. The highest and the lowest organic C contents were found in the C-SR soils from fields no. 6 and 8, respectively.

Irrespective of some differences in chemical properties of the tested soils and the year of study, the lowest contents of microbial biomass C and N were found in soil under winter wheat grown in the monoculture system and the highest values of these microbial parameters were generally detected in the soils of the OR system (Fig. 1). Only in the year 2001 the soils of the OR and C-SR systems contained similar amounts of C and N in microbial biomass. Soil microbial biomass representing the living and most dynamic component of the soil organic matter may also indicate potential biological activity of soil [5, 6, 12]. This activity is reflected by e.g. soil respiration as

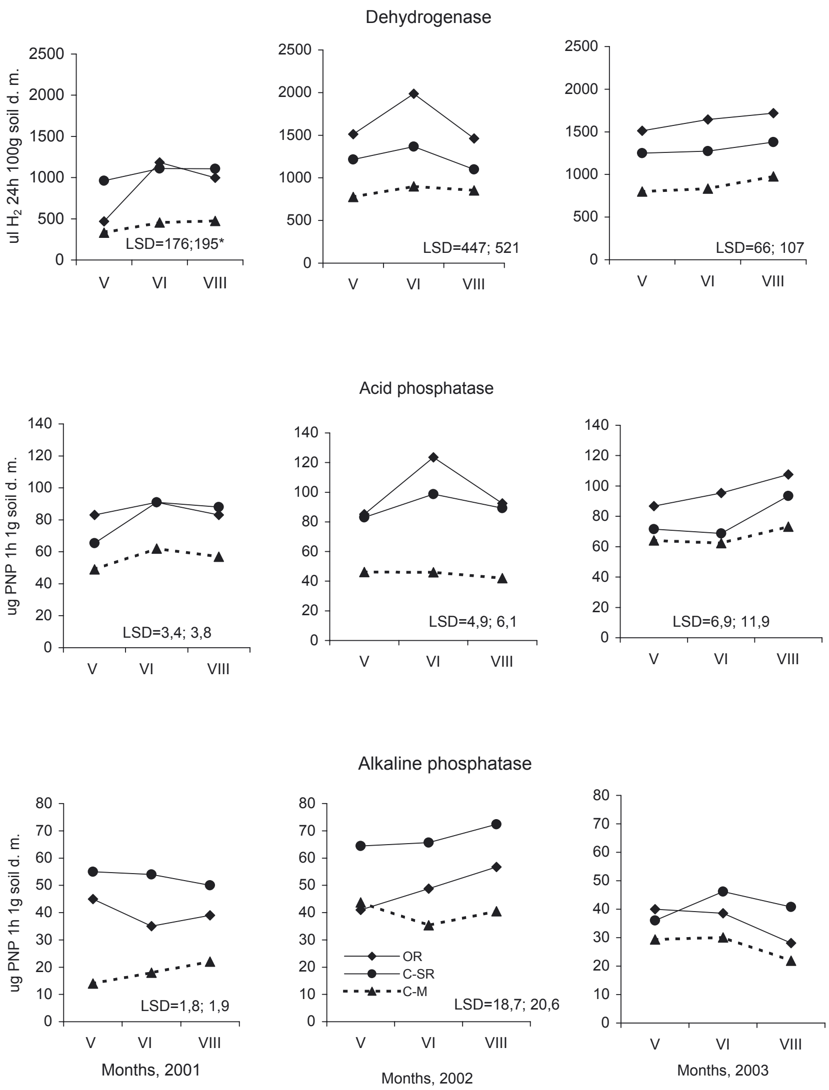

Fig. 2. Enzymatic activity in soil under winter wheat grown in organic (OR), conventional short rotation (C-SR) and conventional monoculture (C-M) farming systems.*LSD (P<0.05) numbers indicate significant differences for interactions date/systems and system/dates, respectively.

Table 1. Some physical and chemical properties of soil under winter wheat grown in different farming systems in 2001-2003 - (depth of sampling 0-20 cm).

Farming system*	Experimental year	Field number	Content of <0.02 mm fraction %	Soil	pH H_2O	Dry weight %	BD** g/cm^3	Organic C %
OR	2001	1	21	light loam	6.1	94.0	1.68	0.76
	2002	3	16	heavy loamy sand	6.6	91.6	1.45	0.94
	2003	2	16	heavy loamy sand	6.4	92.3	1.45	0.89
C-SR	2001	6	16	heavy loamy sand	6.4	95.0	1.58	0.96
	2002	8	19	heavy loamy sand	7.0	93.2	1.52	0.62
	2003	7	16	heavy loamy sand	6.8	94.1	1.63	0.79
C-M	2001-2003	13	15	heavy loamy sand	6.6	95.6	1.65	0.70

* - Farming systems: OR - organic, C-SR - conventional short rotation, C-M - conventional monoculture
** - BD - bulk density of soil

expressed in our studies by CO_2 evolution. Similar to microbial biomass C and N contents, the lowest rate of soil respiration was measured in the C-M soil and the highest respiration rates were detected for the OR soils, with the exception of the year 2001, in which soil respiration was similar in the OR and C-SR systems in all sampling dates (Fig. 1).

Numerous studies showed 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 [1, 2, 3, 4, 14]. In our studies the effect of the applied farming systems on enzymatic activity of soil was also observed (Fig. 2). The enzymatic activity of the soils in our experiment 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 [10], and by the activity of phosphatases, the enzymes that produce nutrient mineralization end liberation of products that are important in plant nutrition [4].

The measurements of dehydrogenase activity performed during 3 years of studies were significantly lower in the soil under winter wheat grown in the C-M farming system, in comparison to the OR, or C-SR systems (Fig. 2). The highest values of dehydrogenase activity were detected most frequently in the soil under wheat in the OR system. As it was shown by Martyniuk et al. [2], Martyniuk et al. [15], Myśków et al. [3], Skujins [16] or Włodarczyk [17], the activity of dehydrogenase, which exists as an integral part of viable soil microorganisms, is often closely related to microbial populations in soils. Probably, significantly lower activity of dehydrogenase in our monoculture-soil was related to lower microbial biomass in this soil as compared the soils in the two other systems (Fig. 1).

Phosphatase enzymes are involved in the P cycle in soil, and especially acid phosphatase provides a potential index of mineralization of soil organic P [4, 18]. In our experiment activities of phosphatases were generally lowest in soil under winter wheat cultivated in the C-M system, similarly to the other microbial parameters measured in these soils (Figs. 1, 2). It is interesting to note that the measurements of alkaline phosphatase activity were highest in soil under wheat grown in the C-SR system, particularly in the years 2001 and 2002 (Fig. 2). The soils of C-SR system analyzed in 2001 and 2002 had almost alkaline reaction and probably this was the reason for the high activity of alkaline phosphatase detected in these soils. Similar results of a close relation between phosphatase activity and soil pH have been presented by Dick [4], Myśków et al. [3], Tabatabai and Bremner [11], Juma and Tabatabai [19, 20].

In our field trial the highest values of activity of dehydrogenase, phosphatases and microbial biomass C and N contents were most often obtained in the organic soil cropped to winter wheat, but the lowest ones occurred in the conventional monoculture soil. Enhanced microbial activity in organic farming systems can be attributed mainly to the application of organic manures and higher amounts of diversified crop residues remaining on the fields than in soil under conventional systems [2, 5, 21]. Moreover, it has been documented [2, 3, 22] that high doses of mineral fertilizers and pesticides, used in conventional farming systems to protect crops against pests and pathogens, might adversely affect the development and activity of the soil biota.

Winter wheat grown in the C-M system produces grain yields markedly lower than those in the C-SR system, and even slightly lower than in the OR system, where no mineral fertilizers and plant protection chemicals are used [23]. Yield declines of cereals grown in the monoculture systems are mainly caused by soil-borne fungal pathogens, which build-up under these conditions [24, 25]. The results of our studies indicate that other disturbances in the monoculture-soil can also occur. Reduced populations (biomass, soil respiration rate) and activity of microorganisms in the monoculture soil may render that soil more favourable to the deleterious microorganisms or decreased nutrient availability to crops.

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