doi: 10.17221/486/2017-PSE

Effects of maize and winter wheat grown under different cultivation techniques on biological activity of soil

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ABSTRACT

Furtak K., Gawryjołek K., Gajda A.M., Gałązka A. (2017): Effects of maize and winter wheat grown under different cultivation techniques on biological activity of soil. Plant Soil Environ., 63: 449–454.

The aim of the study was to compare the activity and functional biodiversity in soil under two different cereals: common maize and winter wheat, both grown in the same pattern of cultivation techniques: conventional (to 25 cm depth) and reduced (to 10 cm depth). Soil samples for comparative analysis were collected at the same time (July 2016) at a long-term field experiment, which was carried out in 2013–2016. Soil biological activity was determined by measurement of dehydrogenases activity (DHa) with TTC (2,3,5-triphenyltetrazolium chloride) application, microbial biomass carbon (MBC) and nitrogen (MBN) content by fumigation-extraction method, and functional diversity of soil microorganisms using the Biolog EcoPlate System. The results demonstrated that the cultivation technique had a greater impact on the soil biological activity, compared to the type of cereal. Higher biological activity was found in the soil under reduced tillage in both cereals. Calculated correlations showed that DHa, MBC, MBN and acid phosphatases were positively correlated with each other. The negative correlation obtained between yield and biological parameters of activity in soil was not expected.

Keywords: *Zea mays*; *Triticum aestivum*; management practices; soil microbial activity

The soil biological activity is very important for both maintaining the soil fertility and for obtaining the high yields. Many cropping factors are known to influence soil structural diversity and biological activity (Czyż and Dexter 2008, Wolińska et al. 2017a). These include cultivation techniques and crop type (Singh et al. 2014, Wolińska et al. 2015, Ba et al. 2016). Cropping system and soil cultivation techniques cause changes in both soil microbial biomass carbon (MBC), as well as in nitrogen (MBN) and organic matter contents, and in respiration and enzymatic activities (Wolińska et al. 2015). It was shown earlier that soil microbial communities depend both on the cultivation techniques and the type of cereal (Govaerts et al. 2007, Oszust et al. 2014). Many studies indicate that conventional cultivation technique and plant monoculture have a negative impact on soil quality (Spedding et al. 2004, Chu et al. 2007, Gajda et al. 2016, 2017, Ba et al. 2016). Such practices are used to increase yields, however, it was estimated that up to 40% of agricultural land in the world has been degraded (Shrestha et al. 2015, Wolińska et al. 2017b).

Cultivated crops can affect the composition and activity of microbial communities in soil through their root exudates and residues. One of the most important cultivated plants is maize (*Zea mays* L.), which is widely used in agriculture and industry. In many countries, maize is grown as monoculture, however, the long-term impact of such management is still not thoroughly investigated (Gałązka et al. 2017b). The second place in the world grain produc-

Supported by the Task 1.3 of the Multi-Annual Programme of the Institute of Soil Science and Plant Cultivation – State Research Institute, Pulawy (IUNG-PIB) and by the IUNG-PIB, Projects No. 2.26 and 2.08.

doi: 10.17221/486/2017-PSE

Table 1. Selected physico-chemical properties of the studied soil (0–20 cm depth)

Treatment		pH_{KCl}	P	K	Mg
			(mg/kg of soil)		
Maize	CT	6.7	103	69	25
	RT	6.5	212	117	21
Winter wheat	CT	6.4	211	103	70
	RT	6.0	164	91	88

CT – conventional cultivation technique; RT – reduced cultivation technique

tion (2016) belongs to wheat (*Triticum aestivum* L.). In Poland winter wheat is the most important cereal in terms of economy. In addition to the largest area of cultivation and harvesting, winter wheat is also characterized by production intensity. This is due to the high soil and precipitation requirements (Saini et al. 1983). These two cereals are grown on a large area of agricultural soils around the world, so it is important to control the effects of their long-time cultivation on soil biological properties.

Consequently, the aim of this study was to evaluate which cereal – maize or winter wheat – has a greater impact on the changes in soil biological activity. In addition, due to the specifics of the field experiment, it compares how the different cultivation techniques affect soil quality under these cereals.

MATERIAL AND METHODS

Field experiment. The research was carried out in 2013–2016 on the long-term field experiment located on a loamy sand soil at the Agricultural Experimental Station (AES) of the Institute of Soil Science and Plant Cultivation in Grabow (51°23'N, 21°38'E), the Mazowieckie voivodeship, Poland. The experiment involved two different cultivation techniques: (1) conventional (CT) and reduced (RT) (area of a single field was 0.5 ha). Winter wheat cv. Jantarka and maize cv. Deliop were grown in monoculture on four separate fields (wheat: W-RT, W-CT; maize: M-RT, M-CT). CT was based on mouldboard ploughing (to 25 cm depth). Additionally, straw after harvest was shredded and turned under. RT was based on a rigid-tine cultivator (to 10 cm depth) and soil crushing-loosening equipment, and the straw was shredded and left on the soil surface. The different soil cultivation techniques from two different experiments are evaluated. Mineral fertilizers were applied to both treatments. Nitrogen was applied to winter wheat at a rate of 150 kg N/ha in 3 doses, while phosphorus and potassium at 40 kg P/ha and 70 kg K/ha. Yearly fertilizer rates supplied to maize were 140 kg N/ha in 2 doses, 80 kg P/ha and 125 kg K/ha. Soil properties and meteorological conditions are presented in Tables 1 and 2.

Soil samples. Soil samples were taken in summer (July) in years 2013–2016. The samples were collected in three replicates (as an average throughout the field) from the 0–20 cm layer (Polish Standard PN-ISO 1038-6, 1998) and sieved through a 2 mm sieve and shortly stored in 4°C until analysis.

Microbial biomass carbon and microbial biomass nitrogen. MBC and MBN contents in soil were measured by the chloroform-fumigation-extraction method (Polish Standard, PN-EN ISO 14240-2, 2011).

Enzymatic activities analysis. The activity of soil dehydrogenases (DHa) was determined spec-

Table 2. The long-term average (1976–2013 and 2013–2016) for monthly mean air temperature and total precipitation during the growing season

	Month					
	IV	V	VI	VII	VIII	IX
Mean air temperature (°C)						
1976–2013	8.2	13.8	16.7	18.6	17.9	13.1
2013–2016	8.9	14.1	17.4	19.8	19.3	15.1
Total precipitation (mm)						
1976–2013	44.0	63.6	78.4	89.7	77.6	62.1
2013–2016	40.3	105.0	75.0	64.0	40.8	48.5

doi: 10.17221/486/2017-PSE

trophotometrically using the TTC (triphenyltetrazolium chloride) as a substrate (Polish Standard, PN-EN ISO 23752-1, 2011) in three replicates. The acid and alkaline phosphatases (AcP, AlP) activities were determined by the ρ-NPP method (Tabatabai 1982) in triplicate.

Biolog EcoPlates analysis. Diversity of the metabolic potential of the soil microbial community was analysed using the Biolog EcoPlate (Biolog Inc., Hayward, USA) method with 31 different carbon sources. Each of the 96 wells of the plate was inoculated with 120 μL of soil inoculums and incubated at 25°C. Absorbance was measured every 24 h at 590 nm with a plate reader MicroStation™ (Biolog Inc., Hayward, USA). On the base of the data obtained at 120 h, the average well colour development (AWCD) and Shannon-Weaver index (H) indices were calculated as given in Garland and Millis (1991).

Statistical analysis. All statistical analyses were performed using the packet Statistica.PL ver. 10.0 (StatSoft Inc., Tulsa, USA). Cluster analysis and heat map were performed on data from the average absorbance values at 120 h (Biolog EcoPlate). The results were submitted to the PC (principal component) analysis in order to determine the common relations between basic parameters of biological activity, including yields and soils collected from different plants and cultivation techniques.

RESULTS AND DISCUSSION

In our study, the highest DHa was observed in soil under both cereals grown in RT. However, soil under winter wheat showed by 60.6% higher DHa than soil under maize (Table 3). Maize produces more root exudates than winter wheat. The root exudates can be a source of easily available nutrients for microorganisms, especially in plant rhizosphere (Wolińska et al. 2017b). Also, the level of MBC and MBN were higher by 40.4% in soil under winter wheat, compared to soil under maize (Table 3). Soil under both cereals grown in RT demonstrated an increasing trend of microbial biomass as compared to CT (by 11.2% under maize, and by 38.2% under wheat, respectively). The observed positive effects of RT on DHa activity in this study were similar to the results obtained by Mikanová et al. (2009), Sikora et al. (2011) and Wolińska et al. (2015). Negative impacts of CT on MBC and MBN contents were also confirmed by numerous studies, e.g. Spedding et al. (2004) and Gajda et al. (2013).

Biolog EcoPlate is a very sensitive method applied for characterization of functional diversity in soil community (Garland and Millis 1991). The time of 120 h was selected for calculation of other indices (Gałązka et al. 2017a). The differences in metabolic activity are presented in Figures 1 and 2. More carbon substrates were consumed by microorganisms from the soil under both cereals grown in RT, but more active were microorganisms in the soil under CT (Figure 1). The AWCD index (Figure 2) was the highest for the soil under winter wheat grown in CT (1.80), while the lowest for the soil under maize grown in RT (1.13). The Shannon's diversity index (Figure 2), remains at similar level for all soil samples, and ranged between 3.31–3.36. The smallest H index value was calculated for the soil under winter wheat grown in CT (3.31), which may suggest that the use of

Table 3. The microbial biomass carbon and nitrogen content and enzymatic activity in soil under winter wheat and maize grown in different cultivation techniques

Cereal	Tillage practice	MBC	MBN	DHa	AlP	AcP
		(μg/1 g DM of soil)		(μg TPF/1 g DM of soil/24 h)	(μg PNP/1 g DM of soil/1 h)	
Maize	CT	71.53[a]	14.99[a]	27.08[a]	20.48[a]	19.29[a]
	RT	80.27[a]	17.11[a]	40.36[b]	17.20[a]	26.79[a]
Winter wheat	CT	98.53[a]	19.30[a]	20.99[c]	42.04[b]	63.07[b]
	RT	159.60[b]	31.33[b]	102.63[d]	35.83[c]	134.45[c]

MBC – microbial biomass carbon content; MBN – microbial biomass nitrogen content; DHa – dehydrogenases activity; AlP – alkaline phosphatase; AcP – acid phosphatase; CT – conventional cultivation technique; RT – reduced cultivation technique; DM – dry mass; TPF – triphenylformazate; PNP – ρ-nitrophenol. Treatment means marked with different letters are significantly different (Tukey's mean separation test, $P \leq 0.05$)

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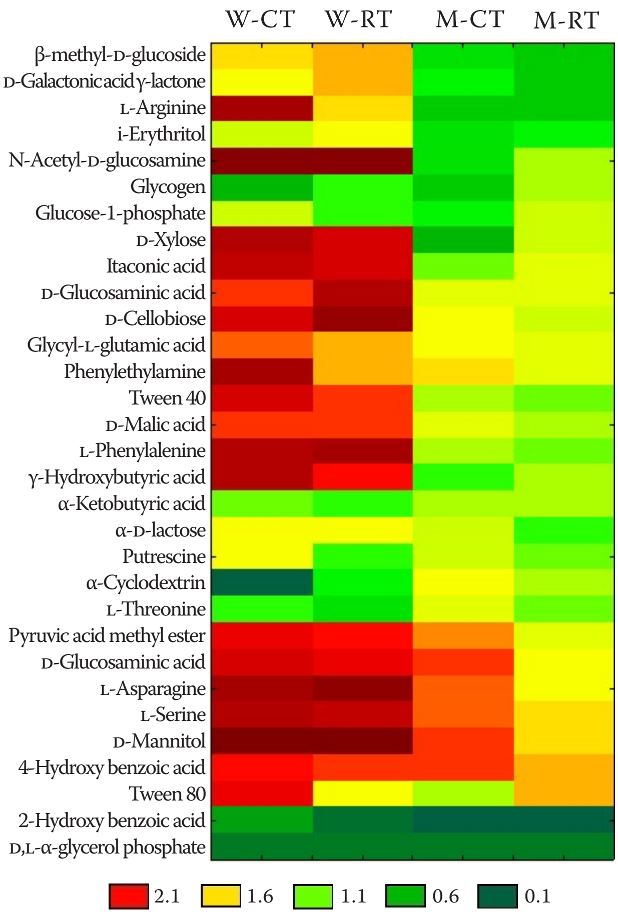

Figure 1. Heat Maps for the carbon utilization patterns of the substrates locates on the Biolog EcoPlates; data from the average absorbance values at 120 h incubated from soil samples; M – maize; W – winter wheat; CT – conventional cultivation technique; RT – reduced cultivation technique

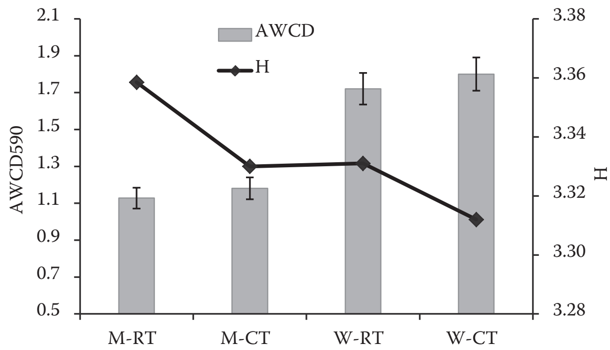

Figure 2. Average well colour development (AWCD) index and Shannon-Weaver index (H) after 120 h incubation; M – maize; W – winter wheat; CT – conventional cultivation technique; RT – reduced cultivation technique. Vertical bars represent the standard error (SE)

CT may have a negative effect on the diversity of microorganisms in the soil (Lupwayi et al. 2001).

The highest utilization of substrates comes from the carbohydrates and amounted 31.3–31.5% (Figure 3). However, C sources the least used by microorganisms in all soil samples were amine and amide group (6.8–8.3%). These results indicate that microorganisms in soil under both cereals do not much differ in their functionality.

To better understand correlation between the basic parameters of biological activity including yields and soils collected from different plants and cultivation techniques, the biplot of principal component analysis was performed. The basic parameters of biological activity and yields explained 97.4% of diversity in soils (Figure 4). Based on biplot PC, the soils were grouped as follows: soils collected from maize cultivation (M-RT and M-CT) and two another groups: soils from wheat in RT and soils from wheat in CT (Figure 4). Calculated correlations showed that DHa, MBC, MBN and AcP were positively correlated with each other. The alkaline phosphatase activity was strongly correlated with yields of both crops. The other parameters negatively correlated with yields, which is an unexpected result (Table 4). Scientific reports rarely show similar results.

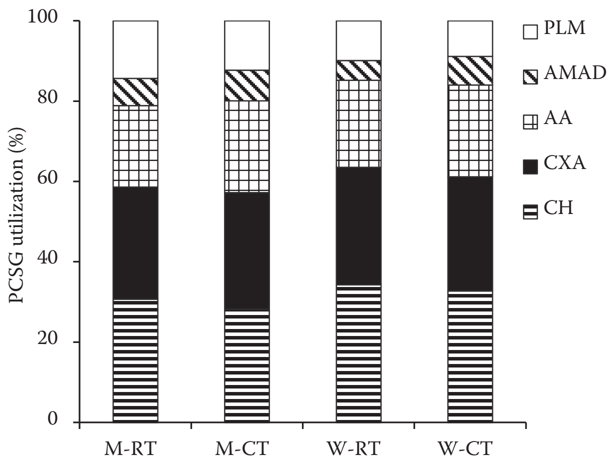

Figure 3. Percentage of utilization of particular carbon substrates groups (PCSG) by microbial communities influenced by different cultivation techniques and type of plant after 120 h of incubation. PLM – polymers; AMAD – amines and amides; AA – amino acids; CXA – carboxylic acids; CH – carbohydrates; M – maize; W – winter wheat; CT conventional cultivation technique; RT – reduced cultivation technique

doi: 10.17221/486/2017-PSE

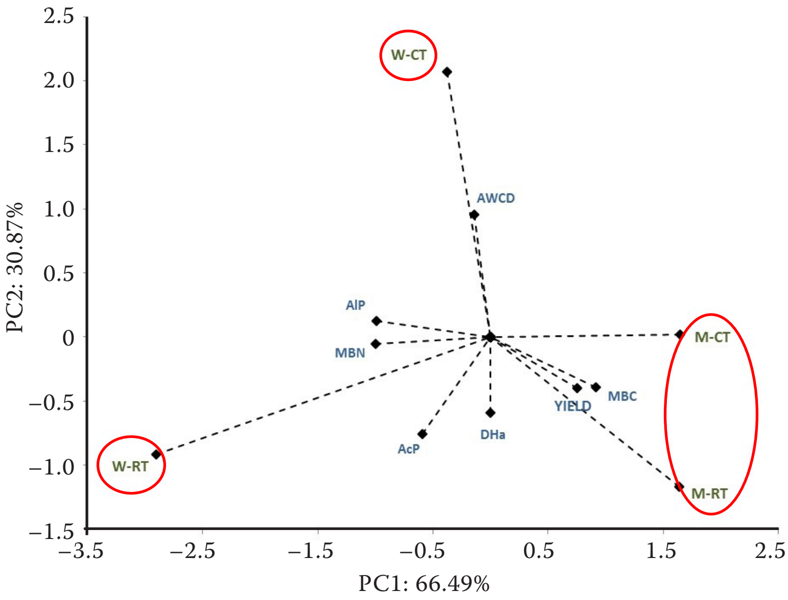

Figure 4. Principal component (PC) analysis of soil parameters. M – maize; WW – winter wheat; CT – conventional cultivation technique; RT – reduced cultivation technique; DHa – dehydrogenases activity; MBC – microbial biomass carbon content; MBN – microbial biomass nitrogen content; AlP – alkaline phosphatase; AcP – acid phosphatase; AWCD – average well colour development index; yield – average for 2013–2016

Lupwayi et al. (2015) received negative correlations for soil microbial biomass content and β-glucosidase enzyme activity with canola yield at fields, where yields were higher than 4 t/ha. The negative correlation, but non-significant ($P > 0.05$) between maize yield and total soil organic carbon, total soil nitrogen and available phosphorus was obtained by Muniafu and Kinyamario (2007). In the research of soil microbial biomass (SMB) C:N ratio on paddy fields, the authors obtained a significant, negative correlation ($r = –0.99$; $P \sim 0.0$) of rice yield with SMB C:N ratio (Li et al. 2016). The researchers suggest that the crop yield mainly depends on the soil moisture content and the ability of the plants to receive light (Zhao et al. 2002, Pandey and Singh 2006).

Our results suggest that soil collected from both cereals grown in the RT was characterized by a higher biological activity than soil under both cereals grown in CT. The cultivation techniques much more differentiated the soil biological activity than the type of cereal. However, the results of Jesus et al. (2016) showed that the plant community was a more important driver of soil microbial communities than the soil type. In our study, the metabolic activities of soil microorganisms indicated by Biolog EcoPlate were significantly higher in the soil under winter wheat than under maize.

In conclusion, the parameters of biological activity measured in this study appeared to be sensitive indicators of changes in soil under maize and winter wheat grown in different cultivation techniques. In particular, dehydrogenases activity and carbon content in biomass of soil microorganisms proved to be the parameters most differentiating changes in the soil under the studied crops.

Table 4. The Pearson's correlation coefficient of yields and biological parameters

Parameter	DHa	MBC	MBN	AcP	AlP	WY	MY
DHa	1	0.904*	0.880*	0.852*	0.213	–0.999*	–0.967*
MBC	–	1	0.947*	0.965*	0.565	–0.996*	–0.268
MBN	–	–	1	0.928*	0.518	–0.989*	0.194
AcP	–	–	–	1	0.663*	–0.957*	–0.972*
AlP	–	–	–	–	1	0.862*	0.996*

*indicated statistically significant at $P \leq 0.05$ ($n = 6$). DHa – dehydrogenases activity; MBC – microbial biomass carbon content; MBN – microbial biomass nitrogen content; AcP – acid phosphatase activity; AlP – alkaline phosphatase activity; WY – winter wheat yield; MY – maize yield

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Received on August 3, 2017
Accepted on October 4, 2017
Published online on October 17, 2017