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Assessment of the glomalins content in the soil under winter wheat in different crop production systems

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ABSTRACT

Gałązka A., Gawryjołek K., Gajda A., Furtak K., Księżniak A., Jończyk K. (2018): Assessment of the glomalins content in the soil under winter wheat in different crop production systems. Plant Soil Environ., 64: 32–37.

The aim of the study was to evaluate the glomalins content (total glomalin (TG), easily extractable glomalin (EEG) and glomalin-related soil proteins (GRSP)) in the soil under winter wheat from different crop production systems. The experiment involved four different cultivation systems: organic, integrated (INT), conventional (CON), monoculture-conventional (MON). The highest content of TG and GRSP proteins were observed in organic system. A strong positive correlation was observed between the total number of glomalins and dehydrogenase activity and organic matter. A strong correlation between TG and GRSP content was observed (r = 0.93) as well as between EEG and GRSP (r = 0.79). The highest yields of winter wheat were observed in CON (9.12 t/ha) and INT (9.04 t/ha) systems, while the lowest in monoculture (4.47 t/ha).

Keywords: *Triticum aestivum*; farming system; arbuscular mycorrhizal fungi; soil quality

Over the recent decades, the world has seen a growing global energy deficit (Wang et al. 2017). The growing costs of agricultural production and the need to protect the environment create the necessity of using farming systems with reduced frequency and intensity of the treatments (Ngosong et al. 2010). Such tillage system should produce low amount of carbon, thus being compatible with the assumptions of organic management systems and sustainable farming (Zarea et al. 2011).

Conventional tillage includes the largest number of crop treatments, which are also performed down to a depth of 25–30 cm (Imadi et al. 2016). Under conventional tillage, the soil is loosened for a long time, and the crop residues can be easily and thoroughly covered (Zarea et al. 2011). This type of cultivation allows a good aeration of the soil and increases its biological activity (Olesen et al. 2011). In spite of this, a slow transition from the ploughing system is justified due to a number of its flaws. One of the main disadvantages of the conventional system is its high energy consumption (Imadi et al. 2016). Soil turning removes the bacterial flora from the lower anaerobic soil layers and the surface bacterial flora is transferred deep beneath the surface (Bedini et al. 2007, Gajda et al. 2017). In modern agriculture, tillage has to meet many conditions to protect the soil and improve its parameters (Qin et al. 2015). First and foremost, it is important to reduce the losses of soil organic

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matter, to improve the soil structure. Also, the content of glomalin in the soil is a very important biological factor in this processes (Bedini et al. 2007, Gałązka and Gawryjołek 2015).

Glomalins are soil glycoproteins produced by arbuscular mycorrhizal fungi (AMF) (Oehl et al. 2011). Glomalins are thermostable, water-insoluble glycoproteins abundantly produced by the *Glomus* fungi and tend to accumulate in the soil that surrounds soil aggregates and protects them from destroying. These proteins have very unique physico-chemical properties performing a fundamental role in making soil structure. It is possible that glomalins are involved in the formation of hydrophobic properties of soil, improving water and air relations in soil. Glomalins occur widely in the soil and constitute a storage for carbon, the source of which is atmospheric CO_2 (Jamiołkowska et al. 2017). The ability to produce and store glomalins in fungal filaments is characteristic only for arbuscular mycorrhizal fungi belonging to the order Glomerales, which includes the family Glomeraceae with the genus *Glomus* (Gillespie et al. 2011). In the natural environment, there is a large diversity of the AMF fungi (Wright et al. 1996). Glomalins are located mainly on the surface of the filaments and spores of the AMF fungi, and as water-repellent, they probably cover the mycelium and protect it against degradation caused by other microorganisms (Wu et al. 2015). The structure of the soil and its chemical characteristics have a significant impact on the mycelium growth, and thus on the glomalin content (Schindler et al. 2007). Functionally, they are proteins connected with soil organic matter, belonging to glomalin-related soil proteins (GRSP) (Tahat and Sijam 2012).

The aim of the present study was evaluation of glomalins content (total glomalin (TG); easily extractable glomalin (EEG) and glomalin-related soil proteins (GRSP)) in the soil under winter wheat from different crop production systems.

MATERIAL AND METHODS

The study was based on the long-term field experiment located on Haplic Luvisol soil at the Experimental Station of Institute of Soil Science and Plant Cultivation, State Research Institute (IUNG-PIB) in Osiny (Lublin voivodeship, Poland; 51°28'N, 22°30'E). The experiment involved four different cultivation systems: organic (ORG); integrated (INT); conventional (CON) and monoculture (MON). Winter wheat cv. Jantarka grew on all these fields. The ORG covered a crop rotation of: potato-spring barley-grass/clover mixture (1st year) – grass/clover mixture (2nd year) – winter wheat, with grass/clover compost (30 t/ha) and without mineral fertilizers. INT was based on the following crops: potato-spring wheat-faba bean-winter wheat with grass/clover compost (30 t/ha). CON was based on mouldboard ploughing (to 20 cm depth) and crop rotation of: winter rape-winter wheat-spring barley. MON consisted of monoculture of winter wheat each year. Soil samples were taken in summer (2015–2016), just before harvest, from the four soil's depths: 0–5, 5–10, 15–20 and 30–35 cm. The soil samples were sieved through a 2 mm sieve and shortly stored in 4°C until analysis. The glomalins content was determined according to the method of Wright et al. (1996). The soil dehydrogenase activity was determined spectrophotometrically using the TTC (triphenyltetrazolium chloride) method (Polish Standard PN-EN ISO 23753-1, 2011). Microbial biomass was determined by the chloroform-fumigation-extraction method (Ghani et al. 2003). The total number of AMF spores was evaluated according to the method of Phillips and Hayman (1970). The content of the POM fraction was measured according to Gajda et al. (2017). Soil organic matter content was measured by wet oxidation using the Tiurin method.

Statistical analyses were performed using the packet Statistica.PL (10) (Stat. Soft. Inc., Tulsa, USA). The analyses were carried out using the ANOVA method and the 95% confidence limit ($P < 0.05$) was chosen to indicate the significance of differences between the studied parameters of soil chemical and biological properties.

RESULTS AND DISCUSSION

The basic chemical parameters of grey-brown podsolic soil were presented in Table 1. The soil taken from the ORG system was characterized by higher content of C_{org} (17 g per 1 kg of soil) and N_{min} = 61.1 kg/ha compared to soils from another crop production systems.

Plants growing in monoculture are usually accompanied by a decrease in soil fertility and productivity, and thus a drop in crop yields. Some studies suggest that growing plants in monocul-

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Table 1. Properties of the 0–30 cm layer of grey-brown podsolic soil (average from 2015–2016)

System	pH_{H_2O}	pH_{KCl}	C_{org} (g per 1 kg of soil)	P_{Egner}	K_{Egner}	Mg	$N\text{-}NH_4$	$N\text{-}NO_3$	N_{min}
				(mg per 1 kg of soil)				(kg/ha)	
ORG	6.61[a]	5.65[a]	17[a]	40.26[b]	63.99[c]	69.3[a]	38.65[a]	22.40[a]	61.1[a]
CON	6.66[a]	5.90[a]	14[b]	84.83[a]	164.00[a]	50.10[b]	35.60[a]	15.10[b]	50.7[b]
INT	6.52[a]	5.75[a]	14[b]	85.44[a]	134.12[a]	41.88[c]	48.50[b]	9.35[c]	57.8[a]
MON	6.05[b]	5.08[b]	13.2[b]	52.27[b]	111.71[b]	46.50[b]	44.05[b]	10.85[c]	54.9[a]

Treatment means separated by different letters are significantly differ (Tukey's mean separation test, $P < 0.05$). ORG – organic; INT – integrated; CON – conventional; MON – monoculture-conventional

ture selects AMF fungi for no active symbionts, as in many cases, a yield decrease is observed under continuous use of this type of cultivation (Imadi et al. 2016). It was found that crop rotation promotes a high variety of AMF types and higher yields of maize and soybeans, both with a higher nutrient content (Gałązka et al. 2017c). The results of our study confirmed that the higher number of AMF spores and also the higher content of glomalins was observed in the ORG system and the lower in monoculture (Table 2). Organic farming system, due to the exclusion of pesticides and fertilizers, does not cause contamination of soil and ground waters with xenobiotics (Olesen et al. 2011). It also reduces leaching of nutrients from the soil and favours the biodiversity of soil microorganisms. Due to that fact that the system of organic growing is based on building a biological balance among all components of field ecosystems and ecosystems adjacent to them. Also the organic system is the most favourable system among the tested ones for the development of AM fungi and the increase in their glomalin production (Bedini et al. 2007). It was proven that cultivation system affects soil aggregation and the length of AM hypha (Driver et al. 2005).

The conventional tillage stimulates the microbiological activity of the soil, which is evidenced by a higher number of microorganisms (Gałązka et al. 2017a). Such stimulation is the result of breakdown of soil aggregates, and hence the exposure and oxygenation of the substances susceptible to degradation. On the contrary, tillage without crop treatments increases microbial activity at or near the soil surface (Gałązka et al. 2017b). In addition, crop treatments, as well as a monoculture, do not favour the development of meso- and macro-fauna of mycorrhizal fungi. This type of tillage breaks macro aggregates, which have the highest rate of mineralization (Wang et al. 2017). A strong positive correlation was observed between the total number of glomalin and dehydrogenase activity and organic matter (Table 3).

Mycorrhizal fungi develop actively mainly in the non-tillage system (Wu et al. 2015). They can cause soil aggregation, increase water penetration, protection of organic matter against decomposition and soil resistance to erosion (Ngosong et al. 2010). Hence, a high concentration of glomalins occurs mainly in the undisturbed, organic systems, due to forming and maintaining sustainability of soil aggregates. The highest contents of total glomalin and GRSP protein were observed in the organic system (Figure 1). The higher content of EEG was observed also in the organic system but no significant differ-

Table 2. The total content of glomalins and the number of arbuscular mycorrhizal fungi (AMF) spores (average from 2015–2016)

System	Glomalin content (mg/g DM of soil)			% of colonization by AMF fungi	Total number of the spore diameter		
	GRSP	TG	EEG		50 um	75 um	150 um
ORG	9.69[a]	6.01[a]	3.91[a]	40.0[b]	449.0[a]	224.0[b]	11.5[b]
CON	9.02[b]	5.10[b]	3.69[b]	41.4[b]	374.5[b]	213.5[b]	10.5[b]
INT	8.67[b]	4.18[c]	3.34[b]	48.0[a]	354.7[b]	264.0[a]	15.5[a]
MON	8.40[c]	5.42[b]	2.97[c]	36.5[c]	240.7[c]	198.5[c]	9.0[c]

Treatment means separated by different letters are significantly differ (Tukey's mean separation test, $P < 0.05$). ORG – organic; INT – integrated; CON – conventional; MON – monoculture-conventional; DM – dry matter

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Table 3. Pearson's correlation coefficients among some properties of soil in Osiny across all treatments and sampling positions in 2015–2016

Parameter	EEG	DHA	MBC	POM	OM
TG	0.894**	0.701**	0.683**	0.493*	0.862**
EEG	1	0.737**	0.807**	0.722**	0.947**
DHA		1	0.962**	0.732**	0.873**
MBC			1	0.824**	0.924**
POM				1	0.791**

**P = 0.01; *P = 0.05; TG – total glomalin; EEG – easily extractable glomalin; DHA – dehydrogenases activity; MBC – microbial biomass of carbon; POM – particulate organic matter; OM – organic matter

ences were found between ORG and CON systems (Figure 1c). Integrated cultivation system, involving a combination of different agricultural treatments, can interfere with the development of fungi, and thus reduce their production of glomalins, resulting in lower levels of this protein in the soil compared to the organic system (Wu et al. 2015).

In the conventional tillage system, where soil aggregates are broken and fungal hypha shredded, the content of glomalins in the soil is low (Schindler et al. 2007). The results of the determination of the glomalins total concentration can be confusing, as the method applied involves extracting the part of the soil organic fraction, which is extremely resistant to adverse conditions, not necessarily glomalins exclusively (Oehl et al. 2011). Hence, GRSP became more reliable in assessing the sustainability of soil aggregates as their values may reflect actual content of glomalins in the soil (Wright et al. 1996). In addition, high concentrations of GRSP and EEG indicate that easily-extractable glomalins fractions can clearly explain the relationship between the glomalins content and agricultural practices (Gillespie et al. 2011).

Taking into account the soil layer, the highest content of glomalins was observed in 0–20 cm (Figure 2a–c). Moreover, on the basis of the regression analysis, a strong correlation between TG and GRSP content was observed (r^2 = 0.87, r = 0.93) (Figure 3a) as well as between EEG and GRSP (r^2 = 0.63, r = 0.79) (Figure 3b).

It is commonly known that the production systems affect the crop yields and crop quality by changing the properties of the soil. Continuous cultivation in monoculture decreases the yields, whereas using crop rotation increases the diversity of AMF types as well as it enhances yield and

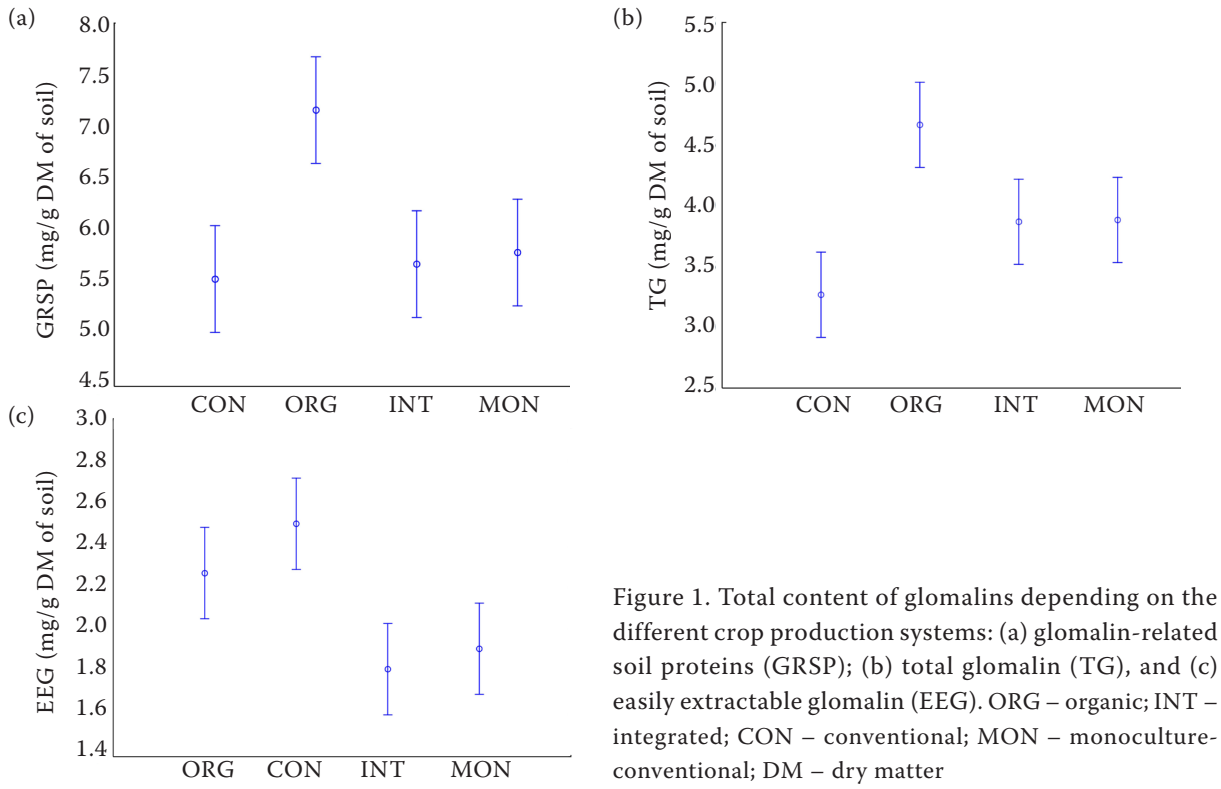

Figure 1. Total content of glomalins depending on the different crop production systems: (a) glomalin-related soil proteins (GRSP); (b) total glomalin (TG), and (c) easily extractable glomalin (EEG). ORG – organic; INT – integrated; CON – conventional; MON – monoculture-conventional; DM – dry matter

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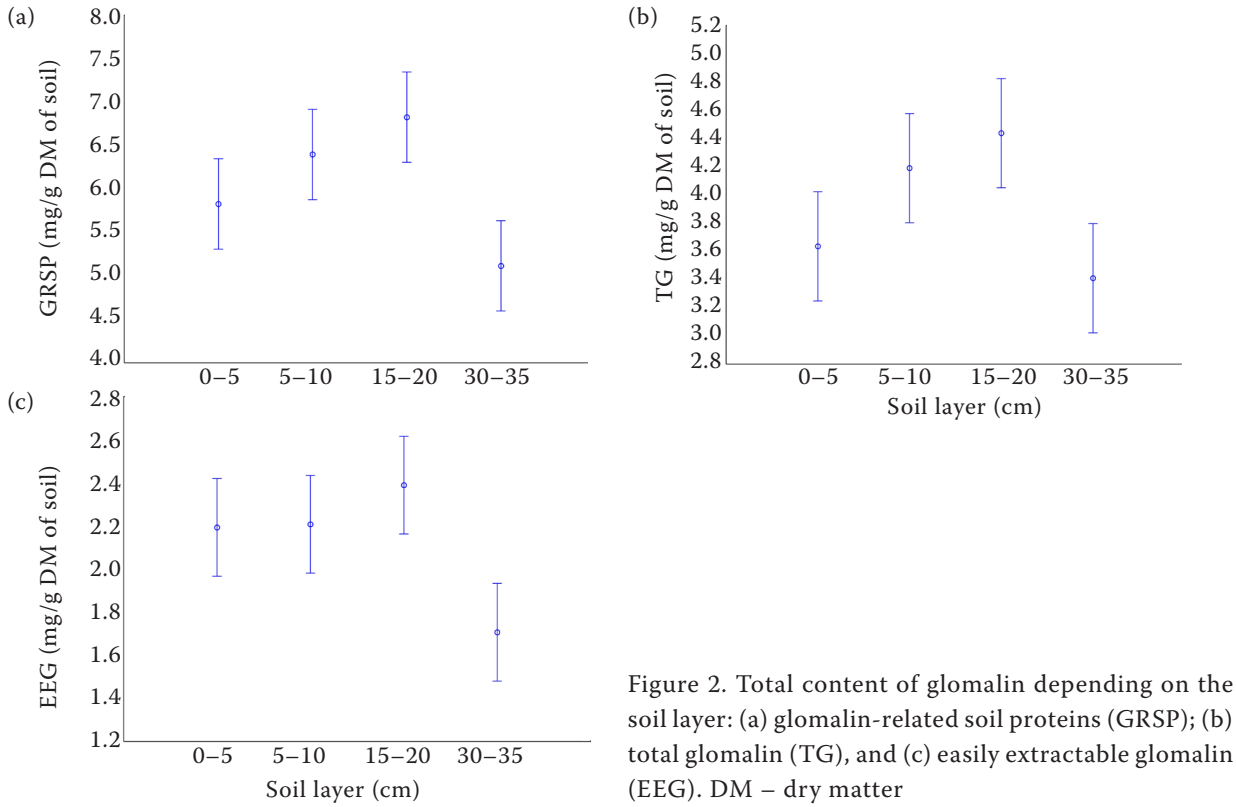

Figure 2. Total content of glomalin depending on the soil layer: (a) glomalin-related soil proteins (GRSP); (b) total glomalin (TG), and (c) easily extractable glomalin (EEG). DM – dry matter

quality of crops (Wright et al. 1996). The results of our study confirmed that the highest yields of winter wheat were observed in CON (9.12 t/ha) and INT (9.04 t/ha) systems, whereas the lowest in monoculture (4.47 t/ha) (Table 4).

The soils used in this experiment were from one geographical area, which is why the differences between the influence of climate and composition of soil components and soil construction were omitted, assuming it was the same for all the samples. Therefore, the concentration of the obtained glomalins in individual cultivation systems reflects only the impact of the system on the development of the AMF fungi and on the increase of their glomalins production. The amount of glomalins produced by the AM fungi depends, among others, on a cultivation system. Organic system greatly increases the production of glomalins and their concentration in the soil, contrary to the integrated cultivation system and monoculture.

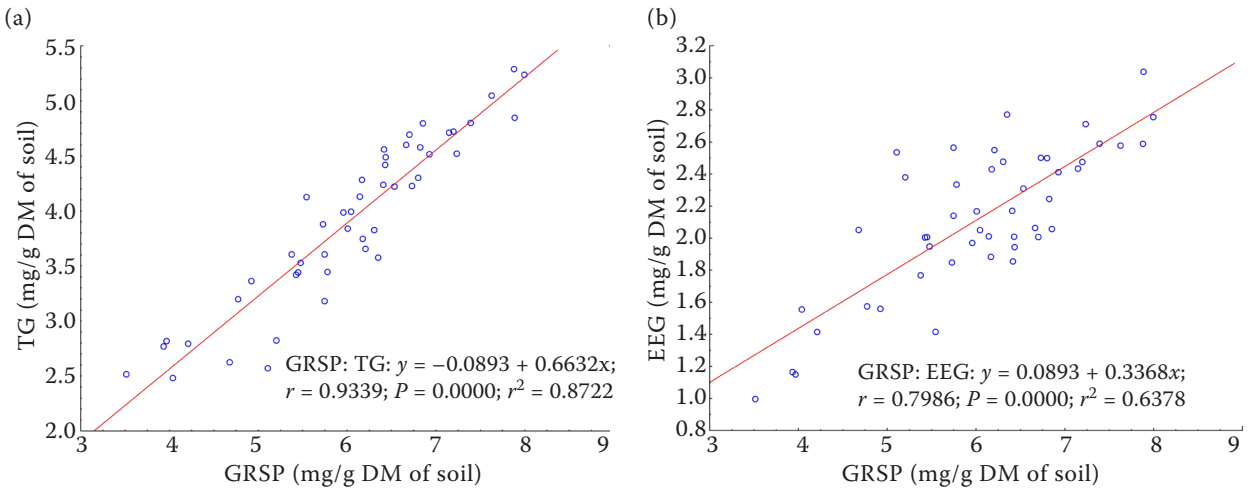

Figure 3. Analysis of regression $P < 0.05$ (a) dependence of total glomalin (TG) on glomalin-related soil proteins (GRSP); (b) dependence of easily extractable glomalin (EEG) on GRSP. DM – dry matter

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Table 4. Effects of different crop production systems on winter wheat yield (average from 2015–2016)

System	Yield (t/ha)	Number of ears per m^2	Thousand grain weight (g)
ORG	7.60[b]	444.0[a]	46.95[a]
CON	9.13[a]	463.5[a]	47.20[a]
INT	9.04[a]	456.0[a]	48.40[a]
MON	4.47[c]	251.5[b]	44.25[b]

ORG – organic; INT – integrated; CON – conventional; MON – monoculture-conventional

REFERENCES

Bedini S., Avio L., Argese E., Giovannetti M. (2007): Effects of long-term land use on arbuscular mycorrhizal fungi and glomalin-related soil protein. Agriculture, Ecosystems and Environment, 120: 463–466.

Driver J.D., Holben W.E., Rillig M.C. (2005): Characterization of glomalin as a hyphal wall component of arbuscular mycorrhizal fungi. Soil Biology and Biochemistry, 37: 101–106.

Gajda A.M., Czyż E.A., Stanek-Tarkowska J., Dexter A.R., Furtak K.M., Grządziel J. (2017): Effects of long-term tillage practices on the quality of soil under winter wheat. Plant, Soil and Environment, 63: 236–242.

Gałązka A., Gawryjołek K. (2015): Glomaline – Glycoprotein produced by mycorrhiza fungus. Postępy Mikrobiologii, 54: 331–343 (in Polish).

Gałązka A., Gawryjołek K., Perzyński A., Gałązka R., Księżak J. (2017a): Changes in enzymatic activities and microbial communities in soil under long-term maize monoculture and crop rotation. Polish Journal of Environmental Studies, 26: 39–46.

Gałązka A., Gawryjołek K., Grządziel J., Frąc M., Księżak J. (2017b): Microbial community diversity and the interaction of soil under maize growth in different cultivation techniques. Plant, Soil and Environment, 63: 264–270.

Gałązka A., Gawryjołek K., Grządziel J., Księżak J. (2017c): Effect of different agricultural management practices on soil biological parameters including glomalin fraction. Plant, Soil and Environment, 63: 300–306.

Ghani A., Dexter M., Perrott K.W. (2003): Hot-water extractable carbon in soils: A sensitive measurement for determining impacts of fertilization, grazing and cultivation. Soil Biology and Biochemistry, 35: 1231–1243.

Gillespie A.W., Farrell R.E., Walley F.L., Ross A.R.S., Leinweber P., Eckhardt K.-U., Regier T.Z., Blyth R.I.R. (2011): Glomalin-related soil protein contains non-mycorrhizal-related heat-stable proteins, lipids and humic materials. Soil Biology and Biochemistry, 43: 766–777.

Imadi S.R., Shazadi K., Gul A., Hakeem K.R. (2016): Sustainable crop production system. In: Hakeem K., Akhtar M., Abdullah S. (eds): Plant, Soil and Microbes. Cham, Springer.

Jamiołkowska A., Księżniak A., Hetman B., Kopacki M., Skwaryło-Bednarz B., Gałązka A., Thanoon A.H. (2017): Interactions of arbuscular mycorrhizal fungi with plants and soil microflora. Acta Scientiarum Polonorum Hortorum Cultus, 16: 89–95.

Ngosong C., Jarosch M., Raupp J., Neumann E., Ruess L. (2010): The impact of farming practice on soil microorganisms and arbuscular mycorrhizal fungi: Crop type versus long-term mineral and organic fertilization. Applied Soil Ecology, 46: 134–142.

Oehl F., Sieverding E., Palenzuela J., Ineichen K., da Silva G.A. (2011): Advances in Glomeromycota taxonomy and classification. IMA Fungus, 2: 191–199.

Olesen J.E., Trnka M., Kersebaum K.C., Skjelvåg A.O., Seguin B., Peltonen-Sainio P., Rossi F., Kozyra J., Micale F. (2011): Impacts and adaptation of European crop production systems to climate change. European Journal of Agronomy, 34: 96–112.

Phillips J.M., Hayman D.S. (1970): Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Transactions of the British Mycological Society, 55: 158–161.

Qin H., Lu K.P., Strong P.J., Xu Q.F., Wu Q.F., Xu Z.X., Xu J., Wang H.L. (2015): Long-term fertilizer application effects on the soil, root arbuscular mycorrhizal fungi and community composition in rotation agriculture. Applied Soil Ecology, 89: 35–43.

Schindler F.V., Mercer E.J., Rice J.A. (2007): Chemical characteristics of glomalin-related soil protein (GRSP) extracted from soils of varying organic matter content. Soil Biology and Biochemistry, 39: 320–329.

Tahat M.M., Sijam K. (2012): Arbuscular mycorrhizal fungi and plant root exudates bio-communications in the rhisosphere. African Journal of Microbiology Research, 6: 7295–7301.

Wang Y.Q., Zhang Y.H., Wang Z.M., Tao H.B., Zhou S.L., Wang P. (2017): Effects of winter wheat season tillage on soil properties and yield of summer maize. Plant, Soil and Environment, 63: 22–28.

Wright S.F., Franke-Snyder M., Morton J.B., Upadhyaya A. (1996): Time-course study and partial characterization of a protein on hyphae of arbuscular mycorrhizal fungi during active colonization of roots. Plant and Soil, 181: 193–203.

Wu Q.S., Li Y., Zou Y.N., He X.H. (2015): Arbuscular mycorrhiza mediates glomalin-related soil protein production and soil enzyme activities in the rhizosphere of trifoliate orange grown under different P levels. Mycorrhiza, 25: 121–130.

Zarea M.J., Karimi N., Goltapeh E.M., Ghalavand A. (2011): Effect of cropping systems and arbuscular mycorrhizal fungi on soil microbial activity and root nodule nitrogenise. Journal of the Saudi Society of Agricultural Sciences, 10: 109–120.

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