Agronomy Research **15**(1), 225–238, 2017

The impact of biological agents on properties of heavy-textured soil and productivity of organically grown crops

A. Łachacz[1], J. Tyburski[2] and K. Romaneckas[3,*]

[1]Department of Soil Science and Land Reclamation, University of Warmia and Mazury in Olsztyn, Plac Lodzki 3, PL10 727 Olsztyn, Poland
[2]Department of Agroecosystems, University of Warmia and Mazury in Olsztyn, Plac Lodzki 3, PL10 719 Olsztyn, Poland
[3,*]Institute of Agroecosystems and Soil Sciences, Aleksandras Stulginskis University, Studentų 11, Akademija, LT53 361 Kaunas distr., Lithuania
[*]Correspondence: kestas.romaneckas@asu.lt

Abstract. Soils with high content of particles φ ≤ 0.02 mm usually have nonfavourable physical and mechanical properties. In order to determine the impact of biological agents on properties of heavy-textured soils in organic farming systems, in the years of 2007–2009 an on-farm scale field experiment was carried out in Budziszewo, Pomeranian province in Poland. The farm was organically managed for 20 years and was characterized by proper management (an appropriate crop rotation and a high stand of dairy cows). Nevertheless, in spring there were problems with soil drying, which used to delay sowing of spring cereals by ca 2 weeks, which in turn resulted in low yielding. Therefore, the following biological agents, i.e. beneficial microorganisms, were applied in 3 consecutive years 3 times each year. Produced on-farm (biodynamic horn preparation) and the others produced by industry under the trademark of: effective microorganism (EM), Humobak and UGmax. In 2007 silage maize was grown, in 2008 – winter spelt wheat and in 2009 – spring common wheat. The soil samples to study soil properties were collected from 5–15 cm soil layer during the vegetation period. The following soil properties were analysed: granulometric composition, bulk density of dry soil, total porosity, soil humidity and air content during sampling, organic matter content, soil pH, content of macroelements (P, K, Mg), soil aggregation based on dry and wet sieving. Moreover in 2009 additional soil samples were taken from an adjusting neighboring field of the conventional farm with the aim of comparing soil physical properties developed both under organic and conventional management.

The authors concluded that the application of above mentioned biological agents did not affect significantly soil properties. The applied agents did not affect crop productivity, with the exception of Humobak which decreased yield of silage maize and spring common wheat in the range of 41, and 26% respectively. A proper organic management as opposed to application of biological agents has positive effect on soil physical properties.

Key words: biological agents, crop productivity, heavy-textured soil, organic farming, soil properties.

INTRODUCTION

Soils with high content of particles φ ≤ 0.02 mm usually have unfavourable physical properties. Nevertheless, besides this fraction there are other factors which affect soil physical properties, like the content of silt (φ 0.002–0.05 mm) and clay (φ < 0.002 mm). Moreover, physical soil properties are modified by chemical soil properties, like content of Ca and other elements (Bronick & Lal, 2005). All these factors affect the soil structure, including the formation of water-proof aggregates. The soil aggregation in turn has a strong impact on soil porosity and possibility of water and gases exchange in the soil.

In organic farming great importance is attached to continuous improvement of soils. The application of organic fertilizers, legumes and green manures cultivation in a crop rotation, lead to an enhancement of the content of soil organic matter. Soil organic matter influences the improvement of numerous chemical, biochemical and physical properties of soil (Rychcik et al., 2006; Romaneckas et al., 2016). Studies on the organic soil management on the physical properties of soils are scarce (Papadopoulos et al., 2014). Organic farming practices usually results in the increase of the content of organic carbon in the soil and of the total soil porosity, as well as in the decrease of bulk soil density. In the study of Papadopuolos (2014) it was proved except the mentioned features, also enhanced aggregate stability. The researches emphasize though that the positive effects of organic farming on soil structure are not necessarily constant over time and are scale dependent.

Producers and dealers of different biological agents often state that the preparations not only improve microbial processes in soil, but also enhance crop's health and growth, soil chemical (increase humus content, nutrients availability) and physical properties (soil structure and water retention) (Koepf et al., 1976; Higa, 2003; Wistinghausen et al., 2007). These studies were focused on soil physical properties, but chemical ones and crop yields were also determined.

The study was done on the farm located in Budziszewo near Jablonowo Pomorskie, on east part of Chelminskie Lakeland (Kondracki, 2000). The farm was organically managed for 20 years and was characterized by a proper management (an appropriate crop rotation and a high stand of dairy cows of 1.8 LU per ha, so farmyard manure was produced and applied on regular basis in high rates). Nevertheless, besides the proper crop rotation and the high rates of farm yard manure (FYM) there were still problems with soil structure, so in the spring time water was stagnating on field surface, and there were problems with too slow soil drying, thus field cultivation and the sowing time were delayed. Sowing of spring cereals was delayed by ca 2 weeks, which in turn resulted in lower yielding. The aim of the study was to evaluate the effect of some biological agents on agrochemical and physical properties of heavy soil and productivity of crops under organic management.

In Poland few biological agents to improve soil biological and physical properties are being used both on organic and conventional farms. An on-farm produced biodynamic horn preparation is obligatory used on biodynamic farms. On both organic and conventional farms industrially produced biological agents were used. EM were commonly used all-over Poland. Humobak was also applied all-over Poland but it was far less common. UGmax was quite commonly used in northern Poland. Since all the above–mentioned biological agents were used on organic farms the authors decided to test their effectiveness.

The authors' main hypothesis states that the use of biological agents can substantially improve soil properties resulting in quicker soil drying after winter, and hence they enable earlier soil tillage and sowing, which in turn could enhance crop yields. The additional hypothesis was that proper organic management has a greater effect on soil physical properties than application of biological agents.

MATERIALS AND METHODS

In September 2007 field and laboratory examination were made to describe soil type of the experimental field on the above mentioned organic farm in Budziszewo, Poland. Hence soil pits were made to determine soil morphology and systematic position. The authors found that soil texture of the top layer (0–30 cm) is L – loam (according to the USDA soil texture classes). The skeletal fraction (φ > 2.00 mm) content is 0%, the sand fraction (φ 2.0–0.05 mm) content is 46%, the silt (φ 0.05–0.002 mm) content is 37% and the clay (φ < 0.002 mm) content is 17%. In the sub-soil layers (30–150 cm) the content of silt and clay fractions are higher, the average silt content is 52%, and the clay content is 35%, and the texture is classified as SiCL – silty clay loam. The soil is classified as *Gleyic Stagnic Eutric Cambisol* (*Loamic*, *Drainic*) according to IUSS Working Group WRB (2014).

In the experimental field silage maize (cv. Reduta) was grown in 2007, in 2008 – winter spelt wheat (cv. Schwabenkorn) followed by white mustard (as green manure) and in 2009 – spring common wheat (cv. Bombona). Silage maize was fertilized with 35 t ha^{-1} of farm yard manure (FYM). Tested biological agents were applied in three consecutive years, 3 times each year: the first time in autumn after harvest of the proceeding crop on its residues, the second time in spring during soil tillage and the third time in full vegetation. The following biological agents were applied: 1) control treatment (CT) (water only), 2) effective microorganism (EM) 3 L ha^{-1}, 3) biodynamic horn preparation (HP) 0.35 kg ha^{-1}, 4) Humobak (HB) 120 L ha^{-1} and 5) UGmax (UG) 3 L ha^{-1}.

In CT plots biological agents were not applied. The biodynamic horn preparation is internationally known as used by biodynamic farmers (Koepf et al., 1976); EM is also quite commonly used (Higa, 2003). Humobak and UGmax are produced and applied in Poland. The first one is a solid, dry microorganism preparation, in which selected microorganism are multiplied on coconut shells. UGmax is also produced in Poland. Composition of applied agents and application methods are given in Table 1. The data on composition of the agents, given by their producers are usually very general (Martyniuk & Ksiezak, 2011), incomplete or lacking. All these soil conditioners are on the positive list as being acceptable to be applied on organic farms in Poland. The online continuously updated list is provided by the Institute of Soil Science and Plant Cultivation in Pulawy, Poland (http//www.iung.pulawy.pl).

The experiment was laid down in completely randomized design in four replications. The experimental field had an acreage of 1.6 ha and a single plot of 800 m^2. Traditinal soil tillage practices were applied. Already in October 2006 25 t of farm yard manure (FYM) per ha was applied and ploughed in. In March 2007 the field was harrowed for the first time and on 26 April the biological agents were applied and on the same day the field was cultivated with cultivator. After 3 days silage maize was drilled and 3-times harrowed in a week and then hoed twice. After harvesting of silage maize in the end of September ploughing was done followed by soil harrowing and drilling of winter spelt wheat. During the vegetation spelt was harrowed twice to control weeds and destroy crusting. In 2008 after spelt harvesting a shallow ploughing was done followed by harrowing and on the same day white mustard for green manure was drilled. In late autumn (November) green manure crops were cut by a disc harrow. After 4 days when green manure was dryer, the field was ploughed. In 2009 in spring time common wheat was drilled. The wheat was harrowed twice.

Table 1. Composition of biological agents applied in the experimental field (2007–2009)

Biological agent	Macro- and microelements, g kg^{-1}					Microorganisms	Application methods
	N	P	K	Mg	Mn		
Effective microorganism (EM)	-	-	-	-	-	Photosynthetic bacteria, *Lactobacillus* spp., yeasts, *Azotobacter* spp.	Mixed and sprayed in 400 L ha^{-1}
Biodynamic horn preparation (HP)	-	-	-	-	-	-	Mixed and sprayed in 400 L ha^{-1}
Humobak (HB)	-	-	-	-	-	-	Spread mechanically, 120 L ha^{-1}
UGmax (UG)	1.2	0.5	3.5	0.1	0.0003	*Lactobacillus* spp., Photosynthetic bacteria, *Azotobacter* spp., yeasts, *Actinomycetes* spp.	Mixed and sprayed in 400 L ha^{-1}

– no data available.

During the vegetation period in July of 2007, 2008 and 2009 soil samples to study physical soil properties were collected from 5–15 cm soil layer, in order to determine soil aggregation. During samples drying alive and dead crop remains (residues) were removed by hand picking. The material after air drying was sieved by a set of sieves of 30.0, 10.0, 7.0, 5.0, 3.0, 1.0, 0.5 and 0.25 mm mesh. From each fraction aggregate sub-samples of 25 g were taken for a wet sieving. The wet sieving was conducted with the use of modified Baksheiev apparatus (so-called soil aggregate separator) constructed in the Institute of Agrophysics of the Polish Academy of Sciences in Lublin, Poland (Walczak & Witkowska, 1976). The modification consisted in adaptation to simultaneous determination of 3 samples instead of one sample. All fractions (excluding fraction below 0.25 mm) obtained after dry sieving were also used for wet sieving. The same set of sieves was used for wet sieving.

Moreover, the soil samples were collected to steel cylinders of 100 cm^3 every year to determine the following physical parameters: the bulk density of dry soil, the total soil porosity, the soil humidity and the air content during soil sampling. The physical soil properties were determined by commonly used methods (Lityński et al., 1976; Ostrowska et al., 1991). The soil texture was determined by aerometric method of Bouyoucos, modified by Casagrande and Prószyński (Lityński et al., 1976) and the sand fraction was determined by the sieving method.

To evaluate quality of the soil structure and the water resistance of soil aggregates, a set of indices was used:

AI_d – aggregation index, dry – a numerical index of aggregation calculated on the basis of 'dry sieving';

AI_w – aggregation index, wet – a numerical index of aggregation calculated on the basis of 'wet sieving'.

The above mentioned indices were elaborated and tested in the Institute of Agrophysics in Lublin, Poland (Dobrzański et al., 1975; Domżał & Słowińska-Jurkiewicz, 1988). While elaborating them, it was assumed that the impact of soil aggregates on soil quality depends on aggregates diameter. Therefore, the indices weights were used – that means, calculating aggregation indices their shares were multiplied by the weights. It was assumed that the most valuable are crumb aggregates of 1–3 mm, and for them the weight 10 was established. The other aggregates have lower weights and aggregates < 0.25 mm and > 10 mm have no weight. The diameters of soil aggregates (mm) and their weights: 7–10 – weight 1, 5–7 – weight 3, 3–5 – weight 8, 1–3 – weight 10, 0.5–1 – weight 5, 0.25–0.5 – weight 3.

The other indices which were used to evaluate the soil quality structure after dry sieving of soil aggregates are as follows: quality structure index – QSI (according to Rewut, 1980) (Eq. 1):

$$QSI = (\varphi\ 0.25\text{–}7.0\ \text{mm}) / (\varphi < 0.25 + \varphi > 7.0\ \text{mm}), \quad (1)$$

where φ is the content of aggregates of a given diameter; clods index – CI (according to Rewut, 1980, cited after Walczak & Witkowska, 1976) (Eq. 2):

$$CI = (\varphi > 10.0\ \text{mm}) / (\varphi < 10.0\ \text{mm}), \quad (2)$$

where φ is the content of aggregates of a given diameter.

In 2009, after elaboration of the 2007–2008 results, the authors decided to take additional soil samples from a neighbouring conventionally managed field of the same soil type. The soil aggregation of that soil was evaluated via dry sieving method.

Besides soil physical parameters, every year soil samples were collected to determine soil chemical properties. The representative soil samples were obtained from the ploughing level (0–20 cm) by the aid of Egner's cane. The taken material was dried to the state of air dry, ground and was sieved by a sieve of 1 mm mesh. Such prepared samples of soil underwent a chemical analysis and there were measured: pH – potentiometrically in suspension of 1 mol KCl dm^{-3} solution and in H_2O; content of available forms of P and K by Egner-Riehm method; content of available forms of Mg by Schachtschabel method; content of organic carbon by Turin method (Lityński et al., 1976; Ostrowska et al., 1991).

The content of organic matter (humus) was calculated by multiplying the content of organic carbon by a conventional factor 1.724. The content of nutrients in the soil was established in a dry matter (a sample dried in temperature of 105 °C).

Every year crop productivity was determined as the last and the most important parameter of soil productivity. It is obvious that crop yields are influenced not only by applied biological agents, but also by weather conditions. The meteorological conditions in vegetative period of 2007, when silage maize was grown, were favourite for this crop it was warmer than usual and the rainfalls were also higher (Table 2). Favourite weather conditions, similar to those in 2007, were also in 2008, when winter spelt wheat was grown. Only in 2009 rainfalls were lower than multi-year average, but their distributions were good, so no negative effect on spring common wheat was found (dry conditions were in harvesting time of cereals).

Table 2. Air temperatures and rainfalls in vegetation periods in 2007–2009

Months	Air temperatures, °C				Rainfalls, mm			
	means	means			sums	sums		
	1961–2000	2007	2008	2009	1961–2000	2007	2008	2009
April	7.9	7.3	7.8	9.7	35.4	26.8	24.2	3.7
May	12.5	13.7	12.5	12.2	57.6	79.7	93.2	89.6
June	15.8	17.5	16.0	14.7	69.5	60.8	83.5	133.1
July	17.2	17.5	21.0	18.9	81.6	176.0	27.1	82.2
August	16.8	18.2	17.3	18.5	75.2	81.0	141.7	25.7
September	12.6	12.6	15.7	14.7	57.1	65.4	105.6	15.6
April–September	12.9	14.5	14.3	14.8	430.4	489.7	509.6	349.9

The silage maize yields were established after weighing of harvested biomass. The common wheat yields were established after weighing of harvested grains after their collecting by a cereals combine harvester. The spelt ears after collecting by cereals combine harvester were hulled in a special machine and then grain yields were weighted.

ANOVA complete randomized design (CRD) was used. To compare differences between means, the significant difference according to Tuckey's *t*-test was calculated at $p = 0.05$.

RESULTS AND DISCUSSION

Soil chemical properties have impact on soil aggregation; The examination of soil chemical properties revealed that the soil had 2.46% of organic matter, which is not much for such a heavy soil, but at the same time much higher than the average for Polish soils (Table 3).

Table 3. Soil chemical properties of the experimental field, 2007 and 2009

Chemical properties		Treatments					Means	$HSD_{0.05}$
		CT	EM	HP	HB	UG		
Organic matter %	2007	2.56	2.49	2.40	2.42	2.44	2.46	n.s.
	2009	2.55	2.50	2.42	2.44	2.43	2.47	n.s.
pH_{KCl}	2007	6.72	6.86	6.44	6.58	6.64	6.65	n.s.
	2009	6.56	6.85	6.38	6.50	6.41	6.54	n.s.
pH_{H2O}	2007	7.32	7.52	7.18	7.25	7.27	7.31	n.s.
	2009	7.23	7.65	7.08	7.17	7.25	7.28	n.s.
P mg kg^{-1}	2007	46.3	48.7	40.3	42.6	45.6	44.7	n.s.
	2009	46.7	48.2	40.8	40.7	46.5	44.6	n.s.
K mg kg^{-1}	2007	148.0	138.8	155.9	152.2	143.0	146.2	n.s.
	2009	142.8	134.5	151.8	150.2	146.1	145.1	n.s.
Mg mg kg^{-1}	2007	60.9	65.7	64.5	67.1	59.5	63.5	n.s.
	2009	60.9	66.3	68.7	67.5	61.8	65.0	n.s.

CT – control treatment, EM – effective microorganisms, HP – biodynamic horn preparation, HB – Humobak, UG – UGmax; n.s. – not significant differences between treatments and years.

The soil pH_{KCl} on the individual experimental plots stood at 6.38 to 6.86, i.e. was close to neutral. Considering though the beneficial influence of calcium ion on the structure quality of heavy soil, it should be stated, that such a soil ought to be periodically limed. It is considered that heavy soils of the pH_{KCl} less than 6.6 should be limed (Fertilizing recommendations, 1985).

The content of crop available phosphorus was at the border of low and medium. Taking into account the heavy texture of the soil, the content of crop available forms of potassium and magnesium should be considered as medium (Fertilizing recommendations, 1985). The authors concluded that the soil chemical properties were favourable to develop a good aggregate structure. After the three vegetation periods in which 3 times each year tested biological agents were applied, soil samples were taken once again and the same chemical analyses were done. The authors did not find any significant effect of agents on the content of soil organic matter, soil pH, the content of available forms of P, K and Mg (Table 3). Wielgosz et al. (2010) on a loamy soil in Lublin province and with rainfall very similar to those in Budziszewo, found initial decrease in soil pH shortly after EM application and then an increasing trend. In the same study EM application initially caused inhibition of soil enzyme activity followed with increasing trends. The same variation pattern (an initial drop followed by increasing trend) was found in the number of physiological groups of bacteria. This may correspond to the opinion of Martyniuk (2011) that the very small number of microorganisms applied to soil (comparing to the number of autochthonic microorganisms living in the soil) and lack of free niches for newcomers results in a very low probability to cause long-term changes in the soil biotope, thus rather short lasting variations may be expected.

The data from the soil physical properties analyses in the first year of investigations (2007) as well as the last one (2009) were presented in this paper. In Table 4 the impact of biological agents on share of aggregate size classes established after dry sieving was shown.

Among the presented aggregate classes the two biggest ones ($\varphi > 10$ mm) indicate a bad soil structure, having unfavourable effect on crops germination and growth. The same holds true for the smallest class ($\varphi < 0.25$ mm), which in fact causes soil dustiness (no aggregate structure). The most valuable soil aggregates are those of diameter between 1 and 5 mm (Dobrzański et al., 1975; Domżał & Słowińska-Jurkiewicz, 1988).

After the 3 years of investigations the authors found no statistically proven impact of the tested biological agents on soil aggregate structure both in the first year of investigation (2007) as in the last one (2009) (Table 4). What can be seen is a tendency of worsening of aggregate structure in the last year of experiment, regardless of applied soil conditioners. This is clearly visible in the biggest aggregates ($\varphi > 30$ mm), so-cold clods. Their share between 2007 and 2009 was more than doubled, although still is not high on that type of soil.

Table 4. The impact of biological agents on soil structure – share of aggregate size classes established after dry sieving, 2007 and 2009

Diameter of aggregates	Year	Treatments					Means	$HSD_{0.05}$
		CT	EM	HP	HM	UG		
>30 mm	2007	3.84	3.40	3.63	3.47	3.69	3.60	n.s.
	2009	4.91	8.58	5.17	11.93	9.43	8.00	n.s.
	mean	4.38	5.99	4.40	7.70	6.56	5.80	-
30–10 mm	2007	22.80	20.69	21.46	22.02	21.91	21.78	n.s.
	2009	14.41	21.04	25.27	19.23	18.03	19.60	n.s.
	mean	18.51	20.87	23.37	20.63	19.97	20.69	-
10–7 mm	2007	9.81	9.25	9.27	9.08	8.27	9.14	n.s.
	2009	8.00	9.85	9.32	9.34	9.26	9.15	n.s.
	mean	8.91	9.55	9.30	9.21	8.77	9.15	-
7–5 mm	2007	7.33	8.80	7.74	8.37	8.47	8.14	n.s.
	2009	9.01	7.92	8.28	6.54	8.68	8.09	n.s.
	mean	8.17	8.36	8.01	7.54	8.58	8.12	-
5–3 mm	2007	7.44	8.22	8.05	7.64	7.43	7.76	n.s.
	2009	8.61	7.53	6.73	6.53	7.26	7.33	n.s.
	mean	8.03	8.88	7.39	7.09	7.35	7.55	-
3–1 mm	2007	21.26	22.79	19.21	21.12	19.57	20.79	n.s.
	2009	29.02	24.33	23.55	26.14	25.25	25.66	n.s.
	mean	25.14	23.56	21.38	23.63	22.41	23.23	-
1–0.5 mm	2007	12.82	13.88	12.67	12.55	13.43	13.07	n.s.
	2009	11.69	9.49	9.75	9.74	10.53	10.24	n.s.
	mean	12.26	11.69	11.21	11.15	11.99	11.66	-
0.5–0.25 mm	2007	6.40	6.09	7.86	6.30	7.84	6.89	n.s.
	2009	6.33	4.66	4.63	4.28	4.69	4.92	n.s.
	mean	6.37	5.38	6.25	5.29	6.27	5.91	-
<0.25 mm	2007	8.30	6.88	10.11	9.45	9.39	8.83	n.s.
	2009	8.02	6.60	7.30	6.27	6.87	7.01	n.s.
	mean	8.16	6.74	8.71	7.86	8.13	7.92	-

CT – control treatment, EM – effective microorganisms, HP – biodynamic horn preparation, HB – Humobak, UG – UGmax; n.s. – not significant differences between treatments and years.

The reason for such a tendency is the crop sequence. Normally on the farm in which the experiments were carried out the following crop rotation is practiced: white clover grass – white clover grass – white clover grass – winter wheat followed by white mustard for green manure – spring wheat – silage maize – winter spelt wheat undersown with clover-grass. In such rotation we have two phases: first of building soil structure and fertility (clover-grass) and second of utilizing (depleting) both soil structure and its fertility (Kiley-Worthington, 1981). In the experiment the rotation was changed to three annual crops in a row, to enable the authors to observe whether applied biological agents could extend the phase of the high good soil structure and to take samples. As was stated before, the soil structure was worsening in time, so the biological agents were not able to stop the process. The question of the role of crop species and fertilization /management practices will be continued towards the end of the article when comparing soil physical properties on organic and conventional farm.

A soil structure quality can be described in the form of soil structure indices. One of them is an aggregation index calculated on the basis of dry sieving (AI_d). The authors found no statistical difference between the control treatment and the treatments with biological agents on AI_d (Table 5). The same applies for the aggregation index calculated on the basis of wet sieving (AI_w).

The values of QSI were not statistically different in the compared treatments. Moreover, a tendency for better values was noticed in the control treatment in the last year of the study. The CI illustrates the ratio of so-cold clod aggregates (φ > 10 mm) to all the other aggregates (φ < 10 mm). The CI index had also a positive tendency of lowering in the control treatment in the last year of the study (Table 5).

Table 5. The impact of biological agents on some indexes of soil structure, 2007 and 2009

Soil structure indexes	Year	Treatments					Means	$HSD_{0.05}$
		CT	EM	HP	HB	UG		
Aggregation index (dry sieving), AI_d	2007	365	417	361	388	383	382	n.s.
	2009	471	399	386	404	413	415	n.s.
	mean	418	408	374	396	398	399	-
Aggregation index (wet sieving), AI_w	2007	2 999	2 832	2 831	2 532	2 887	2 816	n.s.
	2009	3 654	3 356	3 179	3 470	3 259	3 384	n.s.
	mean	3 327	3 094	3 005	3 001	3 073	3 100	-
Quality structure index (QSI)	2007	1.23	1.57	1.38	1.27	1.31	1.35	n.s.
	2009	1.83	1.17	1.12	1.14	1.29	1.31	n.s.
	mean	1.53	1.38	1.25	1.21	1.30	1.33	-
Clods index (CI)	2007	0.36	0.29	0.33	0.34	0.34	0.33	n.s.
	2009	0.24	0.42	0.44	0.45	0.38	0.39	n.s.
	mean	0.30	0.36	0.39	0.40	0.36	0.36	-

CT – control treatment, EM – effective microorganisms, HP – biodynamic horn preparation, HB – Humobak, UG – UGmax; n.s. – not significant differences between treatments and years.

In the case of heavy soils, the bulk density of dry soil should be low. The lower density means the better soil structure. Although some difference between experimental treatments could be seen, they are not statistically significant. The only clear difference is growing of the bulk density between 2007 and 2009 (Table 6). It has nothing to do with the applied treatment, being just a result of soil structure deterioration caused by the increased distance elapsed from clover-grass cropping. The parameter of volume density is connected with total soil porosity. The higher bulk density is the lower soil porosity and the worse conditions for crops growing. The parameter of soil porosity followed the same pattern as bulk density. The same applies to another parameter – the index of soil porosity.

Table 6. The impact of biological agents on some soil physical properties, 2007 and 2009

Physical of soil properties	Year	Treatments					Means	$HSD_{0.05}$
		CT	EM	HP	HB	UG		
Bulk density of dry soil,	2007	1.414	1.323	1.388	1.337	1.367	1.366	n.s.
g cm^{-3}	2009	1.428	1.423	1.409	1.403	1.416	1.416	n.s.
Total soil porosity,	2007	44.50	48.85	49.94	44.77	46.50	46.91	n.s.
% of volume	2009	43.95	44.90	45.67	44.50	44.61	44.73	n.s.
Index of soil porosity,	2007	0.81	0.96	0.89	0.90	0.87	0.89	n.s.
ε	2009	0.79	0.82	0.84	0.81	0.80	0.81	n.s.
Soil humidity,	2007	19.53	15.56	15.79	18.47	17.09	17.29	n.s.
% of volume	2009	29.83	28.56	31.92	29.53	31.25	25.08	n.s.
Air content during	2007	25.12	31.17	35.15	29.71	29.41	30.11	n.s.
sampling, % of volume	2009	14.12	16.34	16.75	16.30	13.36	15.37	n.s.

CT – control treatment, EM – effective microorganisms, HP – biodynamic horn preparation, HB – Humobak, UG – UGmax; n.s. – not significant differences between treatments and years.

The soil humidity was higher in 2007 than in 2009, but in a heavy soil usually air content is the growth limiting factor, rather than humidity. Both parameters are connected, so in 2009 there was higher soil humidity and lower air content. Nevertheless, even the lower air content (on average 15%) was higher than the minimum for good crop growth (10%) and crops development was not limited by oxygen deficit in soil. So, one can conclude that the above discussed parameters were not limiting crop growth (Letey, 1985; Łachacz et al., 2013).

In the literature predominate papers are on the effect of biological agents on soil microbiological properties and crop yields, whereas studies of soil physical properties are scare and contradicting. In the studies of Kaczmarek et al. (2007; 2008) found some contradicting results. In the study of 2007 EM application on light-textured soil resulted in grown soil infiltration, which is a negative effect that might increase drought consequences to crops. In heavy soil infiltration was lower, resulting in slower drying of soil surface after rainfalls, so water can stagnate on fields, postponing spring soil tillage practicing and delaying sowing time. Whereas in the study of Kaczmarek et al. (2008) carried out on different soils, EM application increased infiltration on heavy soil and decreased it on light soil, which is a desired effect.

In our study soil sample examination revealed that although the soil structure was not perfect, but keeping in mind the soil type it was rather good. After a thorough consideration of the soil structure data, the authors came to the conclusion that probably the structure was close to the best that could be achieved on this type of soil. To check this hypothesis it was decided to evaluate the soil structure quality of a neighboring conventional field. The conventional farmer grew crops in the following rotation: silage maize – winter wheat – spring barley – winter oil seed rape – winter wheat. Silage maize was fertilized with 30 t of FYM per ha. The other crops in the rotation were fertilized exclusively with mineral fertilizers. Therefore, the soil samples were taken and a dry sieving was done. It was found that the neighboring conventional field had quite a different soil structure than the organic one (Table 7).

Table 7. Comparison of soil structure – share of aggregate size classes established after dry sieving on organically and conventionally managed fields, 2009

Aggregate diameter, mm	Type of field management		$HSD_{0.05}$
	organic*	conventional	
> 30	4.9	48.3	11.55
10–30	14.4	12.2	n.s.
7–10	8.0	6.4	n.s.
5–7	9.0	5.0	2.00
3–5	8.6	10.3	n.s.
1–3	29.0	8.0	5.50
0.5–1	11.7	5.1	2.79
0.25–0.5	6.3	2.6	1.27
< 0.25	8.1	2.1	1.36
$LSD_{0.05}$	2.44	5.11	–

* – data from the control plots were shown, n.s. – not significant.

The participation of clods (φ > 30 mm) was much higher on the conventional than the organic field (Table 7). The index of soil clods of conventional field was 1.20 that means it was 5-times higher than that of the organically managed soil – 0.24 (data not shown). The other big difference was 3.6 times lower participation of aggregates of diameter 3–1 mm in the conventionally managed fields. At the same time the aggregation index based on dry sieving (AI_d) was two times lower on the conventionally managed field: 471 versus 232 (data is not presented). The above mentioned facts indicate that only this proper organic management (rotation with fertility and soil structure building crops as clover-grass and green manures, fertilization with FYM, non-use of synthetic N) already improved soil structure to probably the best possible level. In that context one may conclude that biological agents could not improve structure of organically managed soil, because it already had the best possible one.

Each year crop productivity was determined as the last and most important parameter of soil quality. In 2007 silage maize was grown giving on average 76.8 t ha^{-1}. Although some variation in yields between the experimental object is visible, statistically lower yields were found only in the object treated with Humobak (Table 8).

Table 8. The impact of biological agents on yielding of crops grown in 2007, 2008 and 2009

Crop production	Treatments					Means	$HSD_{0.05}$
	CT	EM	HP	HB	UG		
Silage maize green mass, t ha^{-1}	81.5	91.5	79.0	48.5	83.5	76.8	13.6
Winter wheat spelt grain*, t ha^{-1}	3.94	4.40	3.97	4.00	4.08	4.08	n.s.
Spring common wheat grain, t ha^{-1}	4.24	3.92	4.13	3.14	4.08	3.90	0.428

* – hulled grain; CT – control treatment, EM – effective microorganisms, HP – biodynamic horn preparation, HB – Humobak, UG – UGmax; n.s. – not significant.

In 2008 winter spelt wheat was grown and high grain yields were harvested. This year no statistical yield difference was found. In 2009 spring common wheat was grown. The lowest yields were harvested on the plots treated with Humobak. To summarize, crop productivity in the three year investigation period, no crop reacted positively on any biological agents applied. At the same time two crops shown negative effect on Humobak application. Lower crop yields were not detected only in 2008. The authors think that the lowering of yields in 2007 and 2009 was caused by the increased microorganism growth, which were blocking availability of nitrogen to crops. In 2008 the nitrogen blocked in 2007 was released, resulting in no yield drop.

The Humobak application resulted in yield lowering also in another study. Babik et al. (2008) in the study done in Skierniewice (Central Poland) on fertile loamy soil used for vegetable growing for many years and similar rainfalls as those in Budziszewo, found 38.8% yield reduction in broccoli due to the Humobak treatment. In the case of chicory and carrots not only Humobak, but also EM caused a yield reduction by ca 13%. Pisikier (2006) found an increase in spring wheat yield, but the results were not confirmed statistically. The wheat was grown on a sandy soil in Pomeranian province in the very similar climate conditions to those in Budziszewo. It is worth mentioning that Humobak was decreasing potato infestation by Colorado Potato Beetle *Leptinotarsa decelineata* (Nowacki et al., 2011). The experiment was done in Jadwisin ca 30 km from Warsaw. The soil was sandy and the climate was little bit milder than in Budziszewo and rainfalls ca 10% lower.

As it was mentioned in our study no effect of UG on crop yield was found. Nevertheless there is also information on positive effect of UGmax application on potato yielding. Zarzecka and Gugała (2012) in the field experiment carried out on a sandy soil in Jadwisin (the same one as in the study of above-cited Nowacki et al., 2011) in 2009–2010 with different potato cultivars found 30–47.9% yield increase. Unfortunately in the paper there is only information about chemical weed control and no information is given whether this high yield increase had something to do with potato infestation by Potato Colorado Beetle as of the above-cited work of Nowacki et al., 2011.

Although in bibliography one can find both positive and negative opinions on effectiveness of biological agents both on soil structure and crop productivity, the negative opinions are more common (Van Vliet at al., 2006; Mayer et al., 2008; Martyniuk, 2011; Martyniuk & Ksiezak, 2011).

Among different biological agents EM was studied in the highest number of experiments. Sulewska & Ptaszyńska (2005) on a sandy soils in the province of Great Poland (little bit milder and dryer climate than in Budziszewo) applied EM in maize growing without yield gain. Just to quote the latest experiments: Rychcik & Sadowski (2011) found no effect of EM application in organic growing of potato and cereals. Sometimes the research findings are contradicted: e.g., Kuś et al. (2013) in the same experiment found no positive effect on wheat yields and 7% yield gain in potatoes and silage maize. The case of maize is very special – although the yield was 7% bigger, the share of cobs in the yield (the most valuable part of the crop) was lower.

CONCLUSIONS

The research hypothesis was that use of biological agents (biodynamic horn preparation, effective microorganism, Humobak and UGmax) can improve a soil quality and enhance crop yields however an application of the above stated biological agents did not affect significantly soil chemical and physical properties. The applied biological agents did not affect crop productivity, with the exception of Humobak which decreased the yield of silage maize and spring common wheat by 41% and 26%, respectively.

A proper organic management (a proper crop rotation with clover-grass and green manure crops, a high stand of livestock and regular farm yard manure fertilization) has much greater positive effect on soil physical properties, as opposed to an application of biological agents.

ACKNOWLEDGEMENTS. The study was conducted with the financial aid of Polish Ministry for Agriculture and Rural Development grants No. HORre-401-177/07, RR-re-401-414/08/485 and RR-re-401-23-171/09. We would like to thank the following students: Ewa Ochrymiuk, Aneta Paulakowska and Tomasz Dmochowski for the help in laboratory analyses.

REFERENCES

Babik, J., Szafirowska, A., Babik, I., Kaniszewski, S., Kłosowski, S., Panasiuk, E. & Sabat, T. 2008. An elaboration of organic vegetables growing techniques for consumption and seed: *Summary of studies on organic farming carried out in 2007.* Warszawa: Press Ministry of Agriculture and Rural Development; pp. 7–15 (in Polish with English translation).

Bronick, C.J. & Lal, R. 2005. Soil structure and management: a review. *Geoderma* **124**, 3–22.

Dobrzański, B., Witkowska, B. & Walczak, R. 1975. Soil-aggregation and water-stability index. *Polish Journal of Soil Science* **8**(1), 3–8.

Domżał, H. & Słowińska-Jurkiewicz, A. 1988. Effect of soil granulometric composition and humus on the number of soil aggregates and their resistance to the water effect. *Rocz. Glebozn – Soil Science Annual.* **39**(3), 5–19 (in Polish with English summary).

Fertilising recommendations. 1985. Part I. The limit numbers for evaluation of the content of macro- and micronutrients. Institute of Soil Science and Plant Cultivation in Pulawy, 34 pp. (in Polish with English translation).

Higa, T. 2003. 38th Int. Microbiological Symp. 'Effective Microorganisms (EM) in Sustainable Agriculture and Environmental Protection'. SGGW, Rogów k/Lodzi, 19 pp.

IUSS Working Group WRB. 2014. *World Reference Base for Soil Resources 2014*. World Soil Resources Reports No 106. FAO, Rome, 191 pp.

Kaczmarek, Z., Owczarek, W., Mrugalska, L. & Grzelak, M. 2007. The influence of effective microorganisms for some of physical and water properties on arable-humus horizons of mineral soils. *Journal of Research and Applications in Agricultural Engineering* **52**(3), 73–77.

Kaczmarek, Z., Jakubus, M., Grzelak, M. & Mrugalska, L. 2008. Impact the addition of various doses of effective microorganisms to arable-humus horizons of mineral soils on their physical and water properties on. *Journal of Research and Applications in Agricultural Engineering* **53**(3), 118–121.

Kiley-Worthington, M. 1981. Ecological agriculture. What it is and how it works. *Agriculture and Environment* **6**, 349–381.

Koepf, H.H., Pettersson, B.D. & Schaumann, W. 1976. *Bio-dynamic agriculture. An introduction*. 429 pp.

Kondracki, J. 2000. *Regional geography of Poland.* Warszawa (in Polish).

Kuś, J., Jończyk, K., Księżak, J., Sadowski, Cz. & Zarzyńska, K. 2013. The influence of soil conditioners (ProBio Ems) on the yielding of winter and spring wheat and potatoes grown organically and conventionally. *The results of studies on organic farming carried out in 2012.* MRiRW, pp. 275–286 (in Polish).

Letey, J. 1985. Relationship between soil physical properties and crop production. *Advances in Soil Science* **1**, 277–294.

Lityński, T., Jurkowska, H. & Gorlach, E. 1976. *The chemical – agricultural analysis*. Warszawa, 332 pp. (in Polish).

Łachacz, A., Kalisz, B. & Poźniak, P. 2013. *Methods of soil fertility improvement in organic farms*. Olsztyn, 83 pp. (in Polish).

Mayer, J., Scheid, S. & Oberholzer, H.R. 2008. How effective are ‘Effective microorganism’? Results from an organic farming field experiment. *16th IFOAM Organic World Congress*, Modena, Italy, pp. 40–43.
Martyniuk, S. 2011. The effective and non-effective microbiological preparations used in crop protection and crop growing, and dependable and unreliable methods of their assessment. *The Progress of Microbiology* **50**(4), 321–328 (in Polish).
Martyniuk, S. & Księżak, J. 2011. Evaluation of quasi microbiological bio-preparations used in crop growing. *Polish Journal of Agronomy* **6**, 27–33 (in Polish with English summary).
Nowacki, W., Goliszewski, W., Zarzyńska, K., Trawczyński, C., Barbaś, P., Szutkowska, M. & Wierzbicka, A. 2011. Irrigation and crop protection in organic farming system to sustain soil productivity, yielding and crops quality (especially potato). *Report from researches in organic farming carried out in 2010.* Ministry of Agriculture and Rural Development, Warszawa, pp. 63–74 (in Polish).
Ostrowska, A., Gawliński, S., Szczubiałka, Z. 1991. *The methods of analysing and assessment of soil and plant properties.* The Institute of Environmental Protection. Warszawa, 334 pp. (in Polish).
Papadopoulos, A., Bird, N.R.A., Withmore, A.P. & Mooney, S.J. 2014. Does organic management lead to enhanced soil physical quality? *Geoderma* **213**, 435–443.
Pisikier, T. 2006. Reaction of spring wheat to the application of bio-stimulators and soil absorbents. *Journal of Research and Applications in Agricultural Engineering* **51**(2), 136–138.
Rewut, I.B. 1980. *The physics of soil*. PWRiL, Warszawa, 383 pp. (in Polish).
Romaneckas, K., Avižienytė, D., Bogužas, V., Šarauskis, E., Jasinskas, A. & Marks, M. 2016. Impact of tillage systems on chemical, biochemical and biological composition of soil. *Journal of Elementolog* **21**(2), DOI: 10.5601/jelem.2015.20.2.923.
Rychcik, B. & Sadowski, T. 2011. The effect of EM application on growth of organic winter wheat and potatoes. *Reports from field research conducted in 2008–2010 (in Polish).* Manuscript available in Department of Agroecosystems, University of Warmia and Mazury in Olsztyn, Poland.
Rychcik, B., Adamiak, J. & Wójciak, H. 2006. Dynamics of the soil organic matter in crop rotation and long-term monoculture. *Plant, Soil and Environment* **52**, 15–20.
Sulewska, H. & Ptaszyńska, G. 2005. The reaction of grain maize on application of microbiological preparations. *Pamiętnik Puławski* **140**, 271–285 (in Polish with English summary).
Van Vliet, P.C.J., Bloem, J. & de Goede, R.G.M. 2006. Microbial diversity, nitrogen loss and grass production after addition of Effective Microorganisms (EM) to slurry manure. *Applied Soil Ecology* **32**, 188–198.
Walczak, R. & Witkowska, B. 1976. The methods of examining and the ways of describing soil aggregation. *The Problems of Agro-physics* **19**, 1–52 (in Polish).
Wielgosz, E., Dziamba, Sz. & Dziamba, J. 2010. Effect of application of EM spraying on the populations and activity of soil microorganisms occurring in the root zone of spring barley. *Polish Journal of Soil Science* **43**, 65–72.
Wistinghausen, C., Scheibe, W., Wistinghausen, E. & Konig, U.J. 2007. Introduction to production of bio-dynamic preparations. *Verlag Lebendige Erde*, Darmstadt, 4th revised edition, 108 pp.
Zarzecka, K. & Gugała, M. 2012. Yielding efficiency of soil conditioner UGmax in potato growing. *Inżynieria Ekologiczna* **28**, 144–148 (in Polish with English summary).