AGRONOMY SCIENCE
wcześniej – formerly
Annales UMCS sectio E Agricultura

VOL. LXXIV (3) 2019

http://dx.doi.org/10.24326/as.2019.3.2

Institute of Soil Science, Engineering and Environment Management,
University of Life Sciences in Lublin, Poland
e-mail: jacek.pranagal@up.lublin.pl

JACEK PRANAGAL, DOROTA TOMASZEWSKA-KROJAŃSKA,
HALINA SMAL, SŁAWOMIR LIGĘZA

Impact of selected waste applications on soil compaction

Wpływ aplikacji wybranych odpadów na zagęszczenie gleby

Summary. In the years 2014–2017, a field experiment was carried out, in which two types of waste were applied to soil. One of them was mineral waste – carboniferous rock from a hard coal mine, and the other – organic waste – post-fermentation sludge from agricultural biogas-producing plant. The experiment was an example of an action, in which soil management was associated with their drainage effects on the soil. The waste was applied to the light soil of low utility value, included in the V bonitation class (in polish soil quality classification) and the 6th complex of agricultural suitability (weak rye). According to the WRB classification, it was Haplic Podzol (PZha) developed from the post-glacial sand. The aim of the study was to analyze changes in soil compaction caused by a single introduction of waste. During the four-year study (2014–2017), the durability of these changes was also observed. It was found that the best effects of reducing the soil compaction were obtained as a result of the combined application of two wastes: carboniferous rock and post-fermentation sludge. Introduction of waste into the soil was also permanent, as differences resulting from the soil management continued in the fourth year of the experiment.

Key words: Haplic Podzol, bulk density, total porosity, carboniferous rock, post-fermentation sludge, waste application

INTRODUCTION

Soil, as the top layer of the lithosphere, is particularly exposed to various pressures, sometimes causing its degradation. It should be remembered that soil resources are considered non-renewable, and soil is a complex and changeable medium [Edwards 2002, Van-Camp et al. 2004, Hillel and Rosenzweig 2012, Lal 2015]. Soil properties can be changed by introducing mineral or organic materials. Waste may also be such materials. As a result, the soil application will reduce their amount directed to landfills. Waste can be then got rid of and at the same time, some properties of arable soils can be improved [Baran et al. 2014, Pranagal et al. 2017, Różyło et al. 2015, 2016]. This is important, among others, due to decreasing amounts of manure produced in recent decades. This determines the search for other sources of organic fertilizers. The condition for using waste for fertilizing and agro-melioration of soils is to meet the ecological safety requirements [Weber et al. 2007, Baran et al. 2008, Minister of Agriculture and Rural Development 2008, Baran et al. 2014].

Soil degradation takes different forms. One of them is physical degradation consisting in excessive soil compaction [Lal 2015]. As shown by Jones [1983], Drewry et al. [2008], McQueen and Shepherd, [2002] and Reynolds et al. [2002, 2008], strong soil compaction in the root zone of crop plants determines their growth. With such a density, one should expect: difficulties in soil aeration, limitation of plants in access to useful water, increase of mechanical resistance in movement of roots in soil mass and disturbances in the development of root system of plants. The abovementioned disturbances in the functioning of the soil-plant-atmosphere system consequently lead to a reduction in yields. Measure of the soil compaction is its bulk density and total porosity. They are one of the most important indicators describing the physical condition of the soil. Their amounts are subject to dynamic changes, both in time and in space. Gradient of the soil density is directed deep into the pedon – density increases with depth. On the other hand, the overall porosity of the soil shows the dynamics of changes opposite to the density. Total porosity is a strongly interdependent feature of the bulk density, with negative correlation ($r \approx -1.0$). In the cultivated soils, the lowest density and the highest general porosity are observed in the top layers immediately after sowing the plants. These features are subject to systematic changes over time, usually until the end of the growing season. Bulk density and total porosity of the soil depend on the mineral composition and particle size distribution of soil material, abundance in organic matter and agrotechnical measures [Jones 1983, Arshad et al. 1996, Logsdon and Karlen 2004, Paluszek 2011, Pranagal 2011].

An interesting pro-ecological strategy is the action of combining two goals. First of all, we strive to improve the soil properties, and secondly, we relieve the environment by minimizing the amount of waste deposited [Baran et al. 2008, 2014, Tomaszewska-Krojańska and Pranagal 2017a, b]. A typical example of this is application research consisting in combining both of these tasks. The research associated with the soil management of waste with their irrigating action was a field experiment, in which two types of waste were used. One of them was mineral waste – carboniferous rock from a hard coal mine, and the other – organic waste – post-fermentation sludge from agricultural biogas-producing plant. The waste was applied to the soil of low utility value, included in the V bonitation class and the 6th complex of agricultural usefulness – weak rye. According to agronomic categories, the examined soil was classified as light. According to WRB [2015], it was Haplic Podzol (PZha) developed from post-glacial sand. The aim of the study was to analyze changes in the soil compaction caused by a single introduction of waste. During the four-year study (2014–2017), durability of these changes was also observed. In this experiment, it was decided to verify the following hypothesis: soil management of waste carboniferous rock and/or post-fermentation sludge will reduce the soil compaction.

MATERIALS AND METHODS

The field experiment was established at the RZD Bezek – 51°12'N, 23°17'E. The research area was located in the mesoregion of Pagóry Chełmskie belonging to the Lublin Upland macro-region. This mesoregion is characterized by a very diverse soil cover, determined mainly by activities of the Central and North Polish continental glacier. The field experiment was established using the random blocks method (in triplicate). Three plants were grown: winter wheat, winter oilseed rape and oats. The soil of experimental field was classified [WRB 2015] as Haplic Podzol (PZha) developed from the post-glacial sand. The soil particle size distribution of Ap level was loamy sand (LS) (2.0–0.05 mm fraction – 75%; 0.05–0.002 mm fraction – 22% and <0.002 mm fraction – 3%). Soil particle density ranged from 2.62 $Mg \cdot m^{-3}$ to 2.64 $Mg \cdot m^{-3}$. According to the utility value, the soil of the tested object was included in the V bonitation class and the complex of agricultural suitability – weak rye. However, according to the category of agronomic weight, it was classified as light soils. The analyzed soil was characterized by strongly acidic reaction (pH_{KCl} = 4.1 ±0.31), and abundance in: organic carbon TOC = 9.5 ±0.68 $g \cdot kg^{-1}$, total nitrogen Nog 0.4 ±0.1 $g \cdot kg^{-1}$, total potassium K = 45.1 ±3.5 $mg \cdot kg^{-1}$, total phosphorus P = 49.4 ±4.8 $mg \cdot kg^{-1}$ and total magnesium Mg = 10.7 ±0.7 $mg \cdot kg^{-1}$ and ratio C/N = 23.8 [Różyło et al. 2015].

Each experimental block with cultivated plants was divided into 5 plots with an area of 37.5 m^2. These plots constituted individual experimental treatments (treatments: A, B, C, D and E). The following scheme has been adopted: treatment A – control soil without additives; treatment B – soil with N (autumn – 40 $kg \cdot ha^{-1}$ and spring – 80 $kg \cdot ha^{-1}$), P (100 $kg \cdot ha^{-1}$), K (120 $kg \cdot ha^{-1}$), Mg (40 $kg \cdot ha^{-1}$), Ca (60 $kg \cdot ha^{-1}$) and S (20 $kg \cdot ha^{-1}$) fertilization; treatment C – soil with carboniferous rock in dose 200 $Mg \cdot ha^{-1}$; treatment D – soil with post-fermentation sediment in dose 60 $m^3 \cdot ha^{-1}$, treatment E – soil with carboniferous rock (200 $Mg \cdot ha^{-1}$) and post-fermentation sediment (60 $m^3 \cdot ha^{-1}$). Treatments C, D and E were fertilized in the same way as treatment B. Waste were evenly distributed on the soil surface. Then, soil cultivation for winter crops was carried out. Mineral fertilizers and waste were applied in late summer in 2013 during the preparation of a field for sowing the winter crops (wheat and rapeseed). The post-fermentation residue originated from the agricultural biogas plant of Wikana Bioenergia Ltd. with headquarters in Siedliszcze in the Lublin province. The substrates used in the fermentation process were: maize silage (70%), sugar beet silage (15%), fruit pomace (5%), dairy waste (5%), and manure (5%). These materials were subjected to mesophilic fermentation at 32–42°C. Dry matter content of the substrates used in the experiment was 8%. Carboniferous rock (directly from rock landfill – not ground) originated from exploitation levels of the hard coal mine owned by Lubelski Węgiel “Bogdanka”. In terms of petrography, it was a mixture of mainly clays and silts.

Soil samples were collected from 0–10 cm and 10–20 cm layers from plots sown with winter plants (wheat and rapeseed) in spring terms: I – 2014; II – 2015; III – 2016 and IV –2017. Studies describing the soil compaction (bulk density – BD and total porosity – TP) included only plots sown with winter plants. Such a procedure was adopted due to the omission of the influence of spring cultivation operations on the soil. To determine the soil compaction, samples with an intact structure were collected into 100 cm^3 metal cylinders, in 6 replicates for each treatment (A, B, C, D and E).

Physical soil properties, such as particle density (PD), bulk density (BD) and total porosity (TP) were studied. The soil physical properties were determined according to the following procedures:

– particle density (PD) – with the pycnometric method ($Mg \cdot m^{-3}$),

– bulk density (BD) – with the gravimetric method, on the basis of the ratio of the mass of soil dried at 105 °C to the initial soil volume of 100 cm^3 ($Mg \cdot m^{-3}$),

– total porosity (TP) was calculated on the basis of results of particle density (PD) and bulk density (BD), $TP = 1-BD/PD$ ($m^3 \cdot m^{-3}$).

The normality of the distribution and homogeneity of variance by Shapiro-Wilk and Levene'a tests were investigated. Results were statistically evaluated with analysis of variance (ANOVA). All pairs of means were compared with Tukey’s test and the lowest significant difference test (LSD). The analysis (two-way ANOVA – treatment × sampling date – year) was performed for the results concerning the soil from the layer (0–20 cm) on four sampling date – year (I–IV). In that manner 6 mean values for each soil property under analysis were compared (Figs 1–4). An estimation was also made of the statistical variation of the results obtained in the experiment, calculating the coefficients of variation CVs = SD (standard deviation) / X (arithmetic mean) (Tabs 1–4), and the coefficients of correlation (r) for the soil properties studied (BD – TP). The statistical evaluation (ANOVA – LSD) and the correlation estimation (r) were conducted assuming the significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

During a four-year field experiment, soil bulk density (BD) results showed low statistical variability. This applied to all BD results, both for soil sown with winter wheat, as well as for winter rape and both analyzed layers (0–10 and 10–20 cm) – CVs < 0.10 (Tabs 1 and 2). In the case of soil under winter wheat, the BD value ranged from 1.51 $Mg \cdot m^{-3}$ (treatment E, III year, layer 0–10 cm) to 1.79 $Mg \cdot m^{-3}$ (treatment C, II year, layer 10–20 cm) (Tab. 1). Bulk density of the soil from the top layer (0–10 cm) was usually lower than in the deeper layer (10–20 cm). For wheat soil, this concerned 18/20 pairs of results subjected to such comparison (Tab. 1). A similar direction of changes in soil density resulting from the enrichment of waste materials (carboniferous rock and/or post-fermentation sludge) was noted on the example of long-term average values for 2014–2017. They were calculated for the whole 0–20 cm cultivated layer. Analysis of these mean BD for soil from beneath wheat showed that the smallest bulk density was on the plots, where the carboniferous rock was applied along with the post-fermentation sludge – treatment E – BD = 1.58 $Mg \cdot m^{-3}$. However, the highest bulk density (BD) was observed in the soil, to which only the carboniferous rock was introduced – treatment C – BD = 1.69 $Mg \cdot m^{-3}$ (Tab. 1). The observed trends of BD changes were also confirmed by statistical analysis (ANOVA – LSD; treatment × sampling date – year) made for average values from the cultivated layer (0–20 cm). According to this analysis, significantly less compact soil was recorded on plots, where two wastes were applied together – treatment E (Fig. 1).

Table 1. Soil bulk density under winter wheat cultivation during four-year study (2014–2017), Mg·m^{-3}

Treatment	Soil layer cm	Sampling date – year				Mean for treatment	CVs
		I	II	III	IV		
A	0–10	1.57	1.72	1.61	1.66	1.67	0.06
	10–20	1.62	1.70	1.68	1.76		
B	0–10	1.70	1.64	1.60	1.55	1.65	0.04
	10–20	1.72	1.69	1.69	1.62		
C	0–10	1.63	1.72	1.69	1.62	1.69	0.04
	10–20	1.65	1.79	1.69	1.70		
D	0–10	1.61	1.66	1.53	1.58	1.62	0.07
	10–20	1.65	1.71	1.55	1.60		
E	0–10	1.60	1.59	1.51	1.55	1.58	0.06
	10–20	1.63	1.63	1.54	1.57		
CVs		0.03	0.04	0.04	0.03		

Explanations for Tables 1–4: A – control soil without additives, B – soil with N, P, K, Mg, Ca and S fertilization, C – soil with carboniferous rock, D – soil with post–fermentation sediment, E – soil with carboniferous rock and post-fermentation sediment; I–IV – sampling date – year: I – 2014, II – 2015, III – 2016 and IV – 2017; CVs – statistical coefficient of variability

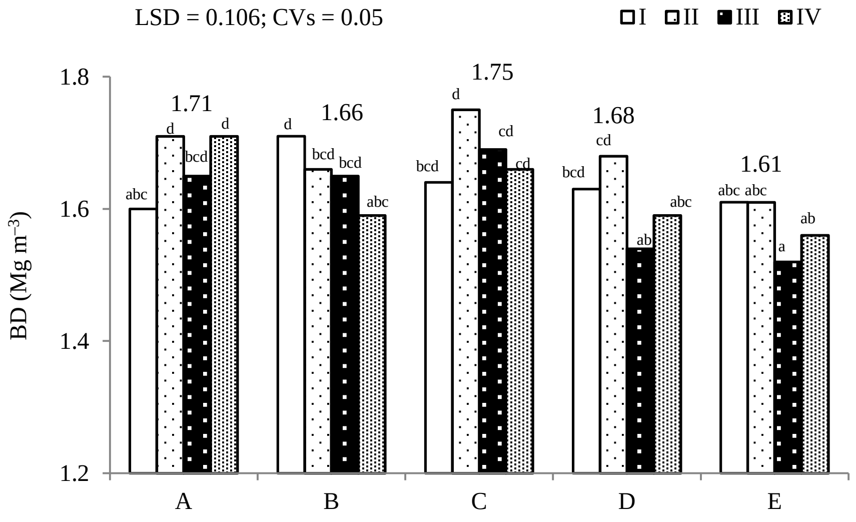

Fig. 1. Average annual soil bulk density (BD) values from the 0–20 cm layer during four-year study (2014–2017) – under winter wheat cultivation

Explanations: A – control soil without additives, B – soil with N, P, K, Mg, Ca and S fertilization, C – soil with carboniferous rock, D – soil with post-fermentation sediment, E – soil with carboniferous rock and post-fermentation sediment; I–IV – sampling date – year: I – 2014, II – 2015, III – 2016 and IV – 2017; CVs – statistical coefficient of variability. Different letters (a, b, c,…cd) mean significant differences (objects/plots × sampling date – year) according to the Tukey's lowest significant difference (LSD)

Soil bulk density under winter rape cultivation showed similar trends of changes as soil under winter wheat. The soil under the oilseed rape was less compacted. BD values ranged from 1.43 Mg·m^{-3} (treatment E, III year, layer 0–10 cm) to 1.69 Mg·m^{-3} (treatment C, I year, layer 10–20 cm) (Tab. 2). Bulk density of soil sown with oilseed rape in a layer of 0–10 cm was lower for each compared 20/20 pair than in the 10–20 cm layer (Tab. 2). According to multi-year averages (2014–2017), BD for the 0–20 cm layer undergoes analogue changes under the influence of soil management, as in the case of the respective BD average for winter wheat. A comparative analysis of these averages showed that the smallest bulk density was also on plots with combined application of two wastes (carboniferous rock and post-fermentation sludge) – treatment E – BD = 1.54 Mg·m^{-3}. The highest BD was recorded in the soil treatments B and C – BD = 1.63 Mg·m^{-3} (Tab. 2). Statistical analysis (ANOVA – LSD) of mean results for the 0–20 cm layer also showed that the treatment E soil was usually significantly less compacted than the treatments A, B and C soil (Fig. 2). The average general values for plants used in the experiment showed that the soil, on which winter oilseed rape was grown, was less compacted than that under winter wheat. Soil bulk density (BD) from beneath rape was on average 1.58 Mg·m^{-3}, while BD under winter wheat cultivation reached an average of 1.64 Mg·m^{-3}. The observed variation in the BD value in individual measurement years (Tabs 1 and 2) also confirms the opinion that soil is a “living” and dynamic creation of nature.

It can be assumed that the BD values obtained in the study were in line with results presented in numerous works [Arshad et al. 1996, Logsdon and Karlen 2004, Drewry et al. 2008, Mueller et al. 2008, Reynolds et al. 2008]. Authors of these studies pointed out that in soils with the particle size distribution of sands and loams, BD reaches most often from 1.50 Mg·m^{-3} to 1.70 Mg·m^{-3} in the cultivated level. Arshad et al. [1996] found that considering the favorable conditions of aeration, the growth of the crop roots, crop yields, availability of nutrients and resistance to water erosion, optimal BD of soils with particle size distribution of loamy sands and sandy loams, should not be higher than 1.60 Mg·m^{-3}. According to Paluszek [2011], the examined soil was characterized by compaction typical for such soils. In his research, the author said that in Poland, cultivated soils with particle size distribution of sands and loams have a density (BD), the values of which range from 1.39 Mg·m^{-3} to 1.79 Mg·m^{-3}. Paluszek [2011], classifying the density of soils from the cultivated level with the particle size distribution of sands and clays, proposed the following division into BD quality classes according to their value: ≤1.40 Mg·m^{-3} – “very low”; 1.41–1.50 Mg·m^{-3} – “low”; 1.51–1.60 Mg·m^{-3} – “medium”; 1.61–1.70 Mg·m^{-3} – “high”; >1.70 Mg·m^{-3} – “very high”. According to this classification [Paluszek 2011], the examined soil from winter wheat was classified in 13/40 cases to the “medium” class; 21/40 – “high” and 6/40 – “very high” (Tab. 1). However, the soil from the plots, where winter oilseed rape was grown, was classified in the “low” class in 3/40 cases; 23/40 – “medium” and 14/40 – “high” (Tab. 2). Based on the results of soil density (Tabs 1 and 2), changes can be presented in the form of a qualitative series for individual treatments A, B, C, D and E. Such series in the sequence from the lowest to the largest soil compaction, takes the form: E > D > A > B > C.

Table 2. Soil bulk density under winter rape cultivation during four-year study (2014–2017), Mg·m^{-3}

Treatment	Soil layer cm	Sampling date – year				Mean for treatment	CVs
		I	II	III	IV		
A	0–10	1.57	1.51	1.53	1.56	1.58	0.04
	10–20	1.59	1.58	1.63	1.64		
B	0–10	1.55	1.62	1.57	1.58	1.63	0.06
	10–20	1.69	1.64	1.65	1.64		
C	0–10	1.60	1.58	1.59	1.60	1.61	0.04
	10–20	1.68	1.62	1.65	1.66		
D	0–10	1.60	1.54	1.45	1.52	1.57	0.05
	10–20	1.61	1.56	1.69	1.56		
E	0–10	1.57	1.52	1.43	1.44	1.54	0.05
	10–20	1.58	1.56	1.63	1.54		
CVs		0.06	0.04	0.08	0.05		

Explanations as in the Table 1

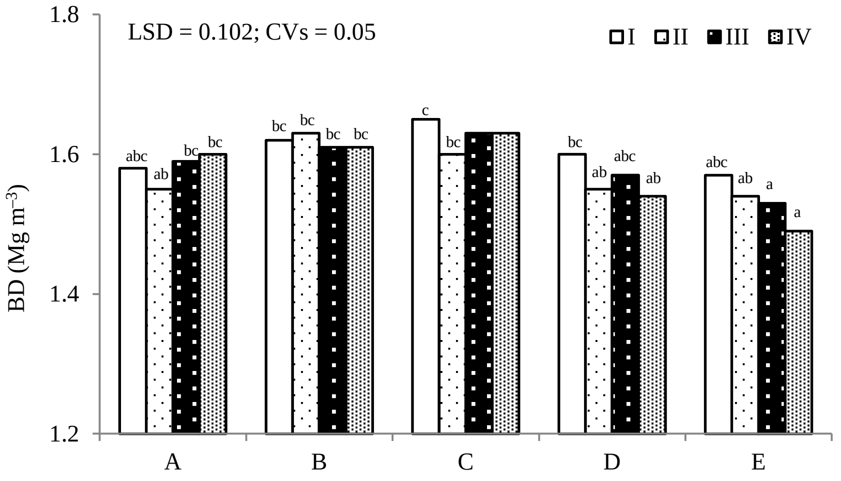

Fig. 2. Average annual soil bulk density (BD) values from the 0–20 cm layer during four-year study (2014–2017) – under winter rape cultivation

Explanations as for Figure 1

Table 3. Total porosity of soil under winter wheat cultivation during four-year study (2014–2017), $m^3 \cdot m^{-3}$

Treatment	Soil layer cm	Sampling date – year				Mean for treatment	CVs
		I	II	III	IV		
A	0–10 10–20	0.403 0.384	0.346 0.354	0.388 0.362	0.369 0.331	0.368	0.10
B	0–10 10–20	0.354 0.346	0.376 0.357	0.392 0.360	0.411 0.386	0.372	0.07
C	0–10 10–20	0.383 0.337	0.348 0.322	0.360 0.360	0.386 0.356	0.357	0.08
D	0–10 10–20	0.388 0.373	0.369 0.350	0.419 0.410	0.399 0.392	0.388	0.11
E	0–10 10–20	0.389 0.378	0.393 0.378	0.424 0.412	0.408 0.401	0.398	0.09
CVs		0.06	0.07	0.07	0.05		

Explanations as in the Table 1

Table 4. Total porosity of soil under winter rape cultivation during four-year study (2014–2017), $m^3 \cdot m^{-3}$

Treatment	Soil layer cm	Sampling date – year				Mean for treatment	CVs
		I	II	III	IV		
A	0–10 10–20	0.403 0.395	0.426 0.399	0.418 0.380	0.407 0.376	0.401	0.05
B	0–10 10–20	0.411 0.364	0.384 0.375	0.403 0.375	0.399 0.379	0.386	0.09
C	0–10 10–20	0.394 0.360	0.402 0.386	0.398 0.375	0.394 0.371	0.385	0.06
D	0–10 10–20	0.392 0.388	0.414 0.407	0.449 0.357	0.422 0.407	0.405	0.08
E	0–10 10–20	0.401 0.397	0.420 0.405	0.454 0.378	0.450 0.412	0.415	0.06
CVs		0.09	0.07	0.12	0.06		

Explanations as in the Table 1

During the four years of research (2014–2017), total porosity (TP) as in the case of bulk density results (BD), was characterized by low statistical variability – CVs < 0.10 (Tabs 3 and 4). On plots with winter wheat, TP was in the range from 0.322 $m^3 \cdot m^{-3}$ (treatment C, II year, layer 10–20 cm) to 0.424 $m^3 \cdot m^{-3}$ (treatment E, III year, layer 0–10 cm) (Tab. 3). TP in 18 cases out of 20 was larger in the 0–10 cm layer compared to the 10–20 cm layer (Tab. 3). The comparative analysis of average TP calculated for the 0–20 cm cultivated layer showed that the application of carboniferous rock with post-fermentation sludge yielded the best effects of reducing the soil compaction – treatment E – TP = 0.398 $m^3 \cdot m^{-3}$. The lowest overall total porosity was found in the soil, to which the carboniferous rock only was introduced – treatment C – TP = 0.357 $m^3 \cdot m^{-3}$ (Tab. 3). Statistical analysis (ANOVA – LSD) carried out for average TP results from the 0–20 cm layer confirmed significant increase in the total porosity of the soil after the combined application of waste – treatment E (Fig. 3).

Volume of all open spaces in the soil, on which winter oilseed rape was grown, was subject to analogous changes as in the case of soil under winter wheat. On the basis of TP results, it was also observed that the soil under rapeseed is less compacted than under wheat. The size of TP fluctuated from 0.360 $m^3 \cdot m^{-3}$ (treatment C, I year, 10–20 cm layer) to 0.454 $m^3 \cdot m^{-3}$ (treatment E, III year, layer 0–10 cm) (Table 4). TP in the 0–10 cm layer was 20/20 higher than in the 10–20 cm layer (Tab. 4). Recorded trends of TP changes in the 0–20 cm cultivated layer were the same as for the soil under winter wheat. The comparison of averages confirmed that the lowest bulk density, and thus the most free space in soil (TP), was after application of the combined soil application of carboniferous rocks with post-fermentation sludge – treatment E – TP = 0.415 $m^3 \cdot m^{-3}$. The lowest overall total porosity was found in the soil with the addition of mineral waste – treatment C – TP = 0.385 $m^3 \cdot m^{-3}$ (Tab. 4). Analysis of variance (ANOVA – LSD) of TP results for the 0–20 cm layer has documented previously recorded effects of agricultural management of carboniferous rock and post-fermentation sludge (Fig. 4). General average TP values for the soil calculated for wheat and rape, also indicated better conditions for plants prevailing under winter rape cultivation. The average TP from rapeseed was 0.399 $m^3 \cdot m^{-3}$, while under wheat, the average TP = 0.377 $m^3 \cdot m^{-3}$.

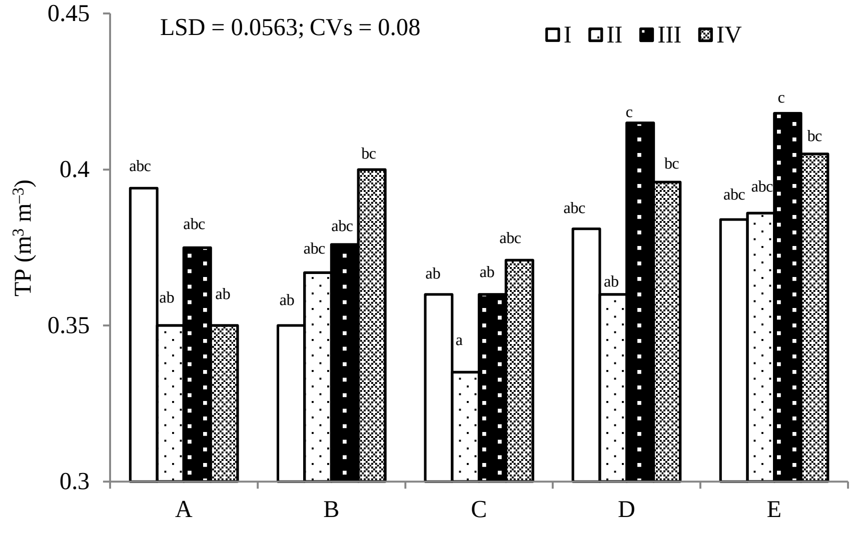

Fig. 3. Average annual soil total porosity (TP) values from the 0–20 cm layer during four-year study (2014–2017) – under winter wheat cultivation

Explanations as for Figure 1

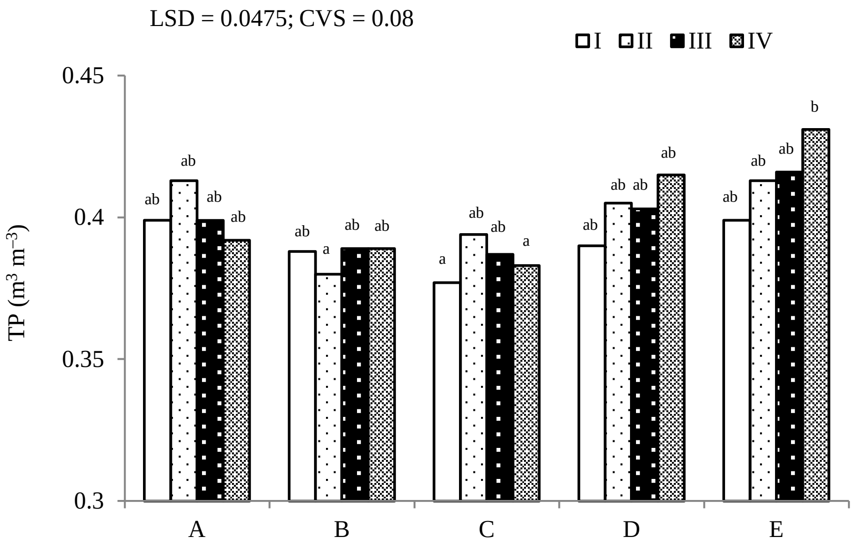

Fig. 4. Average annual soil total porosity (TP) values from the 0–20 cm layer during four-year study (2014–2017) – under winter rape cultivation

Explanations as for Figure 1

Total porosity (TP) as a feature interdependent with soil density (BD × TP – r = –0.986) showed the same trends of changes as BD during the four years of experiment (2014–2017). There was a significant compaction of the analyzed soil and too low value of TP to meet the recommendation by Kowda [1984] and Thompson and Troeh [1978] criterion (TP ≈ 0.500 m^3·m^{-3}) for the "ideal" soil. In the present study, none of the cases (0/40) of mean TP was greater (Tabs 3 and 4) than the indicated minimum [Kowda 1984, Thompson and Troeh 1978]. It should be noted that the provision of air-water favorable conditions for plants in the soil is determined not only by the size of BD and TP, but also by favorable distribution of soil pores and their permeability [Cockroft and Olsson 1997, Olness et al. 1998, Pranagal 2011, Pranagal et al. 2007, Pranagal and Podstawka-Chmielewska 2012, Reynolds et al. 2009, Walczak et al. 2002]. According to Paluszek [2011], the studied soil assumed TP values (Tabs 3 and 4) typical for the levels of cultivated soils with particle size distribution of sands and loams. According to the author's research, the upper levels of cultivated soils in Poland with grains of sands and loams are characterized by total porosity, the values of which are in the range of 0.325–0.468 m^3·m^{-3}. Based on the collected research results, Paluszek [2011] proposed a division into TP quality classes according to their value: ≤0.360 m^3·m^{-3} – "very low"; 0.361–0.390 m^3·m^{-3} – "low"; 0.391–0.420 m^3·m^{-3} – "medium"; 0.421–0.450 m^3·m^{-3} – "high"; >0.450 m^3·m^{-3} – "very high". According to the TP classification proposed by Paluszek [2011], the analyzed soil under cultivation of winter wheat can be classified in 28/40 cases into the "very low" and "low" class; 11/40 – "medium" and 1/40 – "high" (Tab. 3), whereas the soil from winter rape was classified in 14/40 cases to the class "very low" and "low"; 23/40 – "medium" and 14/40 – "high" (Tab. 4). On the basis of results of total porosity of the analyzed soil (Tabs 3 and 4), its changes can also be presented in the form of a qualitative series for individual treatments A, B, C, D and E. This series in the sequence from the lowest to the largest soil compaction will take the following form: E > D > A > B > C.

It should be noted that the discussion of bulk density (BD) and total porosity (TP) results of soil in this experiment focused mainly on highlighting the largest statistically confirmed changes resulting from the soil management of waste materials. Such differences were noted mainly between the soil treatment E (soil enriched with carboniferous rock and post-fermentation sludge) and treatment C (soil with the addition of carboniferous rock). Soil in other analyzed treatments (A, B and D) underwent much smaller changes, which were hardly visible and usually statistically insignificant (Tabs 1–4, Figs 1–4).

CONCLUSIONS

1. The research carried out showed that the single introduction of carboniferous rock and/or post-fermentation sludge into the soil caused changes in its physical condition. This impact was evident both in the separate and combined waste application.

2. The best effect of reducing the soil compaction was obtained as a result of the combined application of two wastes: carboniferous rock and post-fermentation sludge. It was found that this effect was also permanent, because in the fourth year of the experiment, the differences resulting from the soil management of the waste continued.

3. Organic waste – post-fermentation sludge, especially of low moisture content, can definitely be recommended for the use in practice as poor quality light soil conditioner. In contrast, mineral waste – carboniferous rock – should be taken into account when utilizing the soils with a strong particle size distribution.

REFERENCES

Arshad M.A., Lowery B., Grossman B., 1996. Physical tests for monitoring soil quality. In: J.W. Doran, A.J. Jones (ed.), Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ. 49, 123–142.

Baran S., Pranagal J., Bik M., 2008. Usefulness of mineral wool *Grodan* and sewage sludge in management of water properties in soils devastated during extraction of sulphur by Frash method. Możliwości wykorzystania wełny mineralnej Grodan i osadu ściekowego do kształtowania właściwości wodnych w glebach zdewastowanych w procesie wydobycia siarki metodą Frasha. Gospod. Surow. Miner. – Miner. Res. Manag. 24(2/3), 81–95 [in Polish with English summary].

Baran S., Bielińska E.J., Smal H., Wójcikowska-Kapusta A., Paluszek J., Pranagal J., Żukowska G., Chmielewski S., Futa B., 2014. Innowacyjne metody ochrony i rekultywacji gleb. Innovative methods of soils protection and remediation. Komitet Inżynierii Środowiska PAN – Polish Academy of Sciences, Committee of Environmental Engineering, Lublin, 120, 1–260.

Cockroft B., Olsson K.A., 1997. Case study of soil quality in south-eastern Australia: management of structure for roots in duplex soils. In: E.G. Gregorich, M.R. Carter (eds), Soil Quality for Crop Production and Ecosystem Health. Dev. Soil Sci. 25, 339–350.

Drewry J.J., Cameron K.C., Buchan G.D., 2008. Pasture yield and soil physical property responses to soil compaction from treading and grazing – a review. Aust. J. Soil Res. 46, 237–256. doi.org/10.1071/SR07125.

Edwards C.A., 2002. Assessing the effects of environmental pollutans on soil organisms, communities, processes and ecosystems. Eur. J. Soil Biol. 38, 225–231.

Hillel D., Rosenzweig C., 2012. Conclusion: Agricultural solutions for climate change at global and regional scales. In: D. Hillel, C. Rosenzweig (eds), Handbook of Climate Change and Agroecosystems: Global and Regional Aspects and Implications. ICP Series on Climate Change Impacts, Adaptation, and Mitigation 2, Imperial College Press, London, 281–292.

IUSS Working Group WRB, 2015. World Reference Base for Soil Resources 2014, Update 2015. International Soil Classification System For Naming Soils And Creating Legends For Soil Maps. World Soil Resources Reports No. 106. FAO, Rome.

Jones C.A., 1983. Effect of soil texture on critical bulk densities for root growth. Soil Sci. Soc. Am. J. 47, 1208–1211.

Kowda W.A., 1984. Basics of soil science. Podstawy nauki o glebach. PWRiL, Warsaw, Poland [in Polish].

Lal R., 2015. Restoring Soil Quality to Mitigate Soil Degradation. Sustainability 7(5), 5875–5895, https:// doi.org/10.3390/su7055875

Logsdon S.D., Karlen D.L., 2004. Bulk density as a soil quality indicator during conversion to no-tillage. Soil Till. Res., 78, 143–149, https://doi.org/10.1016/j.still.2004.02.003

McQueen D.J., Shepherd,T.G., 2002. Physical changes and compaction sensitivity of a fine textured, poorly drained soil (Typic Endoaquept) under varying durations of cropping, Manawatu Region, New Zealand. Soil Till. Res. 63, 93–107, https://doi.org/10.1016/j.still.2005.04.009

Minister of Agriculture and Rural Development, 2008. Regulation on the implementation of certain provisions of the Act on fertilizers and fertilization of 18 June 2008 (Dz.U. No. 119 item 765 with later d.) – Rozporządzenie Ministra Rolnictwa i Rozwoju Wsi z dnia 16 kwietnia 2008 r. w sprawie szczegółowego sposobu stosowania nawozów oraz prowadzenia szkoleń z zakresu ich stosowania (Dz.U. z 2008 r. Nr 80 poz. 479 z późn. zm., – Dz.U. z 2014 r. poz. 393).

Mueller L., Kay B.D., Been B., Hu C., Zhang Y., Wolff M., Eulenstein F., Schindler U., 2008. Visual assessment of soil structure: Part II. Implications of tillage, rotation and traffic on sites in Canada, China and Germany. Soil Till. Res. 103, 188–196, https://doi.org/10.1016/j.still.2008.09.010

Olness A., Clapp C.E., Liu R., Palazzo A.J., 1998. Biosoild and their effect on soil properties. In: A. Wallace, R.E. Terry (eds), Handbook of Soil Condytioners. Marcel Dekker, New York, 141–165.

Paluszek J., 2011. Criteria of evaluation of physical quality of Polish arable soils. Kryteria oceny jakości fizycznej gleb uprawnych Polski. Acta Agrophys. 191, 1–139 [in Polish].

Pranagal J., 2011. The physical state of selected silty soils of the Lublin Region. Stan fizyczny wybranych gleb pyłowych Lubelszczyzny. Rozprawy Naukowe Uniwersytetu Przyrodniczego w Lublinie – Dissertations, University of Life Sciences in Lublin, Poland, 353, 1–129 [in Polish].

Pranagal J., Podstawka-Chmielewska E., Słowińska-Jurkiewicz A., 2007. Influence on selected physical properties of a Haplic Podzol during a ten-year fallow period. Pol. J. Environ. Stud. 16(2), 875–880.

Pranagal J., Podstawka-Chmielewska E., 2012. Physical properties of a Rendzic Phaeozem during a ten-year period of fallowing under the conditions of south-eastern Poland. Geoderma 189–190, 262–267, https://doi.org/10.1016/j.geoderma.2012.06.023

Pranagal J., Oleszczuk P., Tomaszewska-Krojańska D., Kraska P., Różyło K., 2017. Effect of biochar application on the physical properties of Haplic Podzol. Soil and Tillage Research, 174, 92–103, https://doi.org/10.1016/j.still.2017.06.007

Reynolds W.D., Bowman B.T., Drury C.F., Tan C.S., Lu X., 2002. Indicators of good soil physical quality: density and storage parameters. Geoderma 110, 131–146.

Reynolds W.D., Drury C.F., Yang X.M,, Tan C.S., 2008. Optimal soil physical quality inferred through structural regression and parameter interactions. Geoderma 146, 466–474, https://doi.org/10.1016/j.geoderma.2008.06.017

Reynolds W.D., Drury C.F., Tan C.S., Fox C.A., Yang X.M., 2009. Use of indicators and pore volume-function characteristics to quantify soil physical quality. Geoderma 152, 252–263 https://doi.org/10.1016/j.geoderma.2009.06.009

Różyło K., Oleszczuk P., Jośko I,, Kraska P., Kwiecińska-Poppe E., Andruszczak S., 2015. An ecotoxicological evaluation of soil fertilized with biogas residues or mining waste. Environ. Sci. Pollut. Res. 22(10), 7833–7842, https://doi.org/10.1007/s11356-014-3927-z

Różyło K., Gawlik-Dziki U., Świeca M., Różyło R., Pałys E., 2016. Winter wheat fertilized with biogas residue and mining waste: yielding and the quality of grain. J. Sci. Food Agric. 96(10), 3454–3461, https://doi.org/10.1002/jsfa.7528

Thompson L.M., Troeh F.R., 1978. Soil and soil fertility. McGraw-Hill Inc., New York, 516 pp.

Tomaszewska-Krojańska D., Pranagal J., 2017a. Organizational and legal conditions for the natural management of selected waste. Organizacyjno-prawne uwarunkowania przyrodniczego zagospodarowania wybranych odpadów. Przem. Chem. 96(8), 1629–1631, https://doi.org/10.15199/62.2017.8.XX

Tomaszewska-Krojańska D., Pranagal J., 2017b. Management of carboniferous rock and waste mineral wool in the context of current Polish legislation. Mineralogia 48, 1–4, https://doi.org/10.1515/mipo-2017-0012

Van-Camp L., Bujarrabal B., Gentile A.R., Jones R.J.A., Montanarella L, Olazabal C., Selvaradjou S.K., 2004. Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection. EUR 21319 EN/3, 311–496.

Walczak R., Ostrowski, J., Witkowska-Walczak B., Sławiński C., 2002. Hydrophysical characteristics of Polish mineral arable soils. Hydrofizyczne charakterystyki mineralnych gleb uprawnych w Polsce. Acta Agrophys. 79, 1–64.

Weber J., Karczewska A., Drozd J., Licznar M., Licznar S., Jamroz E., Kocowicz A., 2007. Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts. Soil Biol. Biochem. 39, 1294–1302, https://doi.org/10.1016/j.soilbio.2006.12.005

Financing source: The research was funded with funds for statutory activities of Institute of Soil Science, Engineering and Environment Management, University of Life Sciences in Lublin – RGL/DS/5.

Streszczenie. W latach 2014–2017 przeprowadzono doświadczenie polowe, w którym doglebowo zaaplikowano dwa rodzaje odpadów. Jednym z nich był odpad mineralny – skała karbońska pochodząca z kopalni węgla kamiennego, a drugim odpad organiczny – osad pofermentacyjny z biogazowi rolniczej. Doświadczenie było przykładem działania, w którym skojarzono doglebowe zagospodarowanie odpadów z ich meliorującym działaniem na glebę. Odpady aplikowano do gleby lekkiej, o niskiej wartości użytkowej, zaliczonej do V klasy bonitacyjnej i 6 kompleksu rolniczej przydatności – żytniego słabego. Według klasyfikacji WRB była to Haplic Podzol (PZha) – gleba bielicowa typowa (LWt) wytworzona z piasku polodowcowego. Celem badań była analiza zmian zagęszczenia gleby spowodowanych jednorazowym wprowadzeniem odpadów. Podczas czteroletnich badań (2014–2017) obserwowano także trwałość tych zmian. Stwierdzono, że najlepsze efekty zmniejszenia zagęszczenia gleby uzyskano w wyniku łącznej aplikacji dwóch odpadów: skały karbońskiej i osadu pofermentacyjnego. Wprowadzenie do gleby odpadów miało też trwały charakter, gdyż jeszcze w czwartym roku eksperymentu utrzymywały się różnice wynikające z doglebowego zagospodarowania odpadów.

Słowa kluczowe: Haplic Podzol, gleba bielicowa typowa, bulk density, total porosity, skała karbońska, osad pofermentacyjny, aplikacja odpadów

Received: 5.07.2019
Accepted: 19.09.2019