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THE FORMATION OF SELECTED SOIL PHYSICAL PROPERTIES AFFECTED BY UNDERSOWN SPECIES UNDER ORGANIC WINTER RYE CULTIVATION

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Abstract. Two-factor field experiment was conducted in 2011-2014 and it was designed with split-plot method. The objective of the research was to assess the effect of undersown white clover and common serradella into single-cultivar and three-cultivar mixture of winter rye (*Secale cereale* L.) on selected physical soil properties. Under normal distribution of precipitation, but in the high annual temperatures, the presence of undersown species in rye significantly affected the decrease of soil moisture and the increase in soil compaction. In the remaining years, when more optimal distribution of precipitation and temperatures was noticed, the implementation of white clover and serradella did not affect soil moisture and soil compaction was significantly lower under both undersown species. The implementation of white clover and serradella into agricultural practices of rye did not affect bulk density, although its slight increase was observed. The presence of white clover and serradella in the rye stand significantly increased total and capillary porosity in a 5-10 cm layer. The similar tendency, although statistically not proved, was observed in a 15-20 cm layer.

Key words: bulk density, porosity, serradella, soil compaction, soil moisture, white clover

INTRODUCTION

Apart from the proper crop selection in the organic crop rotation, the other factor of great importance is the implementation of the highest number of cover catch crops and undersown species which are the main source of soil organic matter and they increase the content of humus in soil, especially, in non livestock farming [Siuta 1999, Baldwin and Creamer 2007]. Soil erosion as well as the leaching of nutrients are limited by the

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cultivation of cover catch crops [Hartwig and Ammon 2002, Baldwin and Creamer 2007]. Maintaining the cover crop for a long period of time is the most efficient method of preventing the nitrogen losses in soil and at the same time controlling weed infestation of crops. Ploughed down cover catch crops are also a source of nutrients. Moreover, the role of cover catch crops is to increase the physical, chemical and biological properties of soil which results in higher soil fertility [Hartwig and Ammon 2002].

The beneficial effect of cover catch crops on the soil environment was proved in the extensive research [Wojciechowski 2009]. However, a vast majority of scientists focuses on stubble catch crops and the smaller number of papers deal with the subject of undersown species. But at the same time, the method of undersown species cultivation, which is, first of all, the same cultivation with the crop, seems to form, to a greater extent, the soil environment than a stubble catch crop or the winter cover crop. Moreover, the implementation of undersown species in crop rotation is the cheapest and the easiest method of obtaining the additional biomass because their cultivation does not generate extra costs connected with the preparation of a soil site for sowing, which happens when other types of cover catch crops are used [Woźniak 2000, Płaza *et al*. 2005].

The research hypothesis assumes that the implementation of undersown species in the rye stand will positively affect physical properties of soil. That is why, the aim of the research was to assess the influence of undersown species of white clover and common serradella on the selected, physical properties of soil in a pure crop or three-cultivar winter rye mixture.

MATERIAL AND METHODS

The experiment was carried out in the years 2011-2014 in the Experimental Station "Swojec" belonging to the University of Environmental and Life Sciences in Wrocław, Poland (51º07' N; 17º08'E). It was conducted as a two-factor field experiment designed by a split-plot method with Norfolk organic crop rotation (potato-oats-field pea-rye) and the rye was the tested crop. The main factor was the method of winter rye sowing:

a) pure sowing (one cultivar: Dańkowskie Złote),
b) mixed sowing: (three cultivars: Dańkowskie Złote, Dańkowskie Diament, Walet).

The use of different undersown species was the subplot:

1) control treatment – with no undersown species,
2) common serradella (40 kg·ha^{-1}),
3) white clover (15 kg·ha^{-1}).

The experiment was conducted in three replications (72 plots sowed with the other crops altogether). The area of the plot was 32 m^2. The field experiment was conducted on alluvial sandy loam soil of pH 6,4, according to WRB – fluvisols. The agricultural practices were done according to the valid recommendations for organic farming. Soil was prepared for sowing with combined implement. Winter rye was sown on 27.09.2011, 25.09.2012 and on 28.09.2013 using Wintersteiger® plot seeder, with 12.0 cm row spacing. While selecting the rye cultivars, their potential usefulness for the

extensive agricultural conditions as well as their market accessibility were taken into account.

In the spring, after the start of the growing season in order to improve a health status of rye, the harrowing of stands with the use of a weeder took place. The dates of the treatment in the successive years of the experiment were 05.04.2012, 25.04.2013, 28.03.2014. In the first two years, harrowing was done only once but in the third year it was done twice because of the increased number of weeds. Undersown species were sown into rye by hand two weeks after harrowing.

The research concerning the stands of the cropfield was conducted in all the years of the experiment one day after the rye harvest. The dates of the harvest: 25.07.2012, 27.07.2013, 21.07.2014 were preceded by a five, seven and ten – day period of no rainfall. What determined the date of the research was the fact that the condition of the field during the time of the harvest is a final effect of the ongoing changes during the whole growing season.

The research included:

– the determination of total and capillary porosity, bulk density, soil moisture in 5-10 cm and 15-20 cm layers. The standard soil-core method was used with the cylinders of 100 cm^3 volume with sharpened edges which were hammered into the soil, dug out and trimmed whereupon their contents were weighed – with actual content of water, after capillarity and after drying in 105ºC;
– the determination of soil compaction with the use of compaction probe in 0-20 cm layer, every 5 cm.

Compaction probe is the metal impact probe acting as the energy of a weight with a known mass (1 kg) falling from a certain height (60 cm) which drives a measuring cone into the soil.

Statistical analysis

Selected physical properties of soil were found to have equal variances and normal distributions and were analyzed by ANOVA. In those analyses in which the *F* test indicated a significant difference among the method of sowing and undersown species, the means were separated by the least significant difference (LSD) at a 5% probability level.

The weather conditions during the experiment were based on the data from Agrometeorological Station belonging to the Institute of Environmental Protection and Development.

The frequency analysis to calculate the probability of exceedence per each year of experiment for the total annual rainfall and temperatures was conducted [Raes, 2013]. It was carried out for 46 years, from 1968-2014. Probability of exceedence was estimated by determining the plotting position of annual rainfall and temperature data in ascending order and in accordance with the equation:

$$Pe = M/(N + 1)\cdot 100$$

where:

Pe – probability of exceedence, %,
M – rank number $1 < M < 46$,
N – number of annual rainfall and temperatures records ($N = 46$).

If Pe is less than 20% for a given year, than rainfall or temperature is wetter or warmer than normal. If it is more than 80% the rainfall is dryer and temperature colder than normal.

The research seasons 2011/2012, 2012/2013, 2013/2014 were examined against a background of the years 1968-2014 and gained respectively the following Pe in relation to precipitation: 44.7%, 6.4%, 29.8% and as far as temperatures are concerned: 19.1%, 48.9%, 4.3%. According to Pe 201120/12 season showed normal Pe for precipitation and the sum of temperatures just slightly lower than normal. The second year of research showed most abundant rainfall, while the temperatures were normal. The last season 2013/2014 showed normal Pe for precipitation, but Pe showed very high temperatures (the second ranking number against a background of 46 years).

RESULTS

The significant differences in soil moisture under experimental factors were only observed in 2014 (Table 1). In the both tested layers it was noticed that under mixture sowing the soil moisture was significantly lower than in the plots sown with one species of rye by 8.0 and 8.7% respectively. Moreover, the implementation of undersown species into the rye resulted in the significant decrease in soil moisture.

Table 1. Soil moisture, $cm^3 \cdot 100\ cm^{-3}$
Tabela 1. Wilgotność gleby, $cm^3 \cdot 100\ cm^{-3}$

Undersown species Gatunek wsiewki	Year – Rok								
	2012			2013			2014		
	method of rye sowing – sposób siewu żyta								
	pure czysty	mixed miesz.	mean średnia	pure czysty	mixed miesz.	mean średnia	pure czysty	mixed miesz.	mean średnia
	layer – warstwa 5-10 cm			layer – warstwa 5-10 cm			layer – warstwa 5-10 cm		
No undersown – Brak wsiewki	13.5	13.4	13.5	14.2	14.9	14.6	13.3	14.1	13.7
White clover – Koniczyna biała	13.9	13.1	13.5	12.9	14.0	13.5	11.1	8.8	9.9
Serradella – Seradela	13.6	14.4	14.0	13.6	13.1	13.4	9.0	7.9	8.5
Mean – Średnia	13.7	13.6		13.6	14.0		11.2	10.3	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla									
method of sowing – sposobu siewu		ns – ni			ns – ni			0.4	
undersown species – wsiewki		ns – ni			ns – ni			1.3	
interaction – interakcji		ns – ni			ns – ni			ns – ni	
	layer – warstwa 15-20 cm			layer – warstwa 15-20 cm			layer – warstwa 15-20 cm		
No undersown – Brak wsiewki	14.8	15.2	15.0	15.9	16.7	16.3	15.3	15.2	15.3
White clover – Koniczyna biała	15.0	15.8	15.4	15.7	16.1	15.9	14.2	12.0	13.1
Serradella – Seradela	14.6	16.5	15.6	15.4	15.2	15.3	12.1	10.4	11.3
Mean – Średnia	14.8	15.8		15.7	16.0		13.8	12.6	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
method of sowing – sposobu siewu		ns – ni			ns – ni			0.7	
undersown species – wsiewki		ns – ni			ns – ni			0.8	
interaction – interakcji		ns – ni			ns – ni			1.2	

ns – ni – not significant difference – różnice nieistotne
miesz. – mieszanina

In the more shallow layer the presence of white clover significantly decreased soil moisture by 27.7%, and the presence of serradella decreased it as much as by 40.0% in comparison with the conditions in the plots sown only with rye. In the layer of 15-20 cm the significant interaction of experimental factors was observed: in the pure crop as well as in the cultivar mixture, the lowest level of soil moisture was noticed in the serradella plots. White clover also decreased the soil moisture in comparison with the plots where there was not such an element of crop rotation.

Bulk density was not significantly modified under the experimental factors (Table 2). What might be observed is the fact that the implementation of undersown species in the rye stand, in general, encouraged the slight decrease in bulk density.

Table 2. Soil bulk density, $g \cdot cm^{-3}$
Tabela 2. Gęstość objętościowa gleby, $g \cdot cm^{-3}$

Undersown species Gatunek wsiewki	Year – Rok								
	2012			2013			2014		
	method of rye sowing – sposób siewu żyta								
	pure czysty	mixed miesz.	mean średnia	pure czysty	mixed miesz.	mean średnia	pure czysty	mixed miesz.	mean średnia
	layer – warstwa 5-10 cm			layer – warstwa 5-10 cm			layer – warstwa 5-10 cm		
No undersown – Brak wsiewki	1.69	1.66	1.68	1.64	1.62	1.63	1.69	1.71	1.70
White clover – Koniczyna biała	1.63	1.61	1.62	1.60	1.60	1.60	1.61	1.62	1.62
Serradella – Seradela	1.68	1.62	1.64	1.59	1.64	1.62	1.70	1.65	1.68
Mean – Średnia	1.67	1.63		1.61	1.62		1.67	1.66	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla									
method of sowing – sposobu siewu		ns – ni			ns – ni			ns – ni	
undersown species – wsiewki		ns – ni			ns – ni			ns – ni	
interaction – interakcji		ns – ni			ns – ni			ns – ni	
	layer – warstwa 15-20 cm			layer – warstwa 15-20 cm			layer – warstwa 15-20 cm		
No undersown – Brak wsiewki	1.73	1.76	1.75	1.72	1.73	1.73	1.74	1.74	1.74
White clover – Koniczyna biała	1.71	1.71	1.71	1.70	1.69	1.70	1.73	1.73	1.73
Serradella – Seradela	1.72	1.70	1.71	1.72	1.71	1.72	1.76	1.72	1.74
Mean – Średnia	1.72	1.72		1.71	1.71		1.74	1.73	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
method of sowing – sposobu siewu		ns – ni			ns – ni			ns – ni	
undersown species – wsiewki		ns – ni			ns – ni			ns – ni	
interaction – interakcji		ns – ni			ns – ni			ns – ni	

ns – ni – not significant difference – różnice nieistotne
miesz. – mieszanina

In the first two years of research, it was shown that in a 5-10 cm layer the significant difference in total porosity was caused by the presence of additional species in the rye stand (Table 3). The presence of white clover and serradella significantly increased porosity by 7.7% and 5.7% in 2012 and 9.5% and 7.2% in 2013 respectively.

In the last year of the research no significant differences in porosity caused by the implementation of undersown species in the rye stand were observed. However, the direction of changes proved in the previous years was maintained. It also concerned porosity tested in the deeper layer.

Table 3. Total soil porosity, %
Tabela 3. Porowatość ogólna gleby, %

Undersown species Gatunek wsiewki	Year – Rok								
	2012			2013			2014		
	method of rye sowing – sposób siewu żyta								
	pure czysty	mixed miesz.	mean średnia	pure czysty	mixed miesz.	mean średnia	pure czysty	mixed miesz.	mean średnia
	layer – warstwa 5-10 cm			layer – warstwa 5-10 cm			layer – warstwa 5-10 cm		
No undersown – Brak wsiewki	35.1	34.8	35.0	35.0	34.1	34.6	34.7	33.8	34.3
White clover – Koniczyna biała	37.4	38.0	37.7	37.9	37.8	37.9	37.8	37.5	37.6
Serradella – Seradela	37.2	36.7	37.0	36.9	37.2	37.1	34.4	36.2	35.3
Mean – Średnia	36.6	36.5		36.6	36.4		35.7	35.8	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla									
method of sowing – sposobu siewu		ns – ni			ns – ni			ns – ni	
undersown species – wsiewki		1.6			2.1			ns – ni	
interaction – interakcji		ns – ni			ns – ni			ns – ni	
	layer – warstwa 15-20 cm			layer – warstwa 15-20 cm			layer – warstwa 15-20 cm		
No undersown – Brak wsiewki	32.6	32.4	32.5	33.4	33.7	33.6	32.8	33.0	32.9
White clover – Koniczyna biała	35.4	35.9	35.7	35.1	35.2	35.2	33.1	33.0	33.1
Serradella – Seradela	35.4	34.2	34.8	34.4	34.6	34.5	32.0	33.6	32.8
Mean – Średnia	34.5	34.2		34.3	34.5		32.7	33.2	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
method of sowing – sposobu siewu		ns – ni			ns – ni			ns – ni	
undersown species – wsiewki		ns – ni			ns – ni			ns – ni	
interaction – interakcji		ns – ni			ns – ni			ns – ni	

ns – ni – not significant difference – różnice nieistotne
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The similar correlations were shown for another parameter defining physical properties of soil such as capillary porosity (Table 4). This porosity retains the water required for plants growth. It becomes filled with air as the plant extracts the water from these fine pores. The water in these pores in not lost by the forces of gravity.

In the experiment, capillary porosity was significantly modified in the more shallow of the examined layers while using undersown species. Just like in the case of total porosity, the differences were proved statistically in the first and in the second year of the research. Then, sharing the same area by cereal and undersown species resulted in the significant increase in capillary porosity by 5.3% in 2012 and 7.4% in 2013 for white clover and by 5.0% and 6.5% for serradella respectively. In 2014, the tendency of the increase in capillary porosity while using undersown species continued. The direction of changes was also similar in a 15-20 cm layer, especially, in the first two years of the research.

The undersown species in all the years of the research and in each of the examined layers significantly affected the soil compaction (Table 5). The method of rye sowing also affected this parameter, but only in 2013 and 2014, and not in all of the examined layers. In 2012 and 2013 it was the presence of white clover which modified the soil compaction to greatest extent, causing its significant decrease in comparison with the pure rye stand.

Table 4. Capillary soil porosity, %
Tabela 4. Porowatość kapilarna gleby, %

Undersown species Gatunek wsiewki	Year – Rok								
	2012			2013			2014		
	method of rye sowing – sposób siewu żyta								
	pure czysty	mixed miesz.	mean średnia	pure czysty	mixed miesz.	mean średnia	pure czysty	mixed miesz.	mean średnia
	layer – warstwa 5-10 cm			layer – warstwa 5-10 cm			layer – warstwa 5-10 cm		
No undersown – Brak wsiewki	34.1	34.2	34.2	34.1	33.2	33.7	38.0	33.8	35.9
White clover – Koniczyna biała	34.6	37.3	36.0	35.8	36.6	36.2	39.8	37.5	38.6
Serradella – Seradela	36.1	35.7	35.9	36.0	35.8	35.9	36.8	36.2	36.5
Mean – Średnia	34.9	35.7		35.3	35.2		38.2	35.8	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla									
method of sowing – sposobu siewu		ns – ni			ns – ni			ns – ni	
undersown species – wsiewki		1.1			1.8			ns – ni	
interaction – interakcji		ns – ni			ns – ni			ns – ni	
	layer – warstwa 15-20 cm			layer – warstwa 15-20 cm			layer – warstwa 15-20 cm		
No undersown – Brak wsiewki	30.3	31.0	30.7	32.2	32.5	32.4	38.0	39.7	38.9
White clover – Koniczyna biała	33.2	34.1	33.7	33.7	33.5	33.6	38.7	39.4	39.0
Serradella – Seradela	32.8	32.1	32.5	33.4	34.7	34.1	37.1	38.9	38.0
Mean – Średnia	32.1	32.4		33.1	33.6		37.9	39.3	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
method of sowing – sposobu siewu		ns – ni			ns – ni			ns – ni	
undersown species – wsiewki		ns – ni			ns – ni			ns – ni	
interaction – interakcji		ns – ni			ns – ni			ns – ni	

ns – ni – not significant difference – różnice nieistotne
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The presence of serradella in the rye stand in those years also significantly affected the decrease in soil compactness (only in a 10-15 cm layer in 2013, despite the fact that the tendency of decreasing in soil compaction while using serradella continued, its significance was not shown). In 2013, in a 15 -20 cm layer, the significant influence of the method of rye sowing on soil compaction was also noticed. Rye in mixture caused its decrease by 0.9% in comparison with the pure crop. In 2014 the use of undersown species increased significantly the soil compaction in all the examined layers. In a 0-5 cm layer, the implementation of white clover resulted in more than a double increase in soil compaction, and of serradella by 88.8% in relation to the observed soil compaction with no undersown species.

In another two layers, both experimental factors made a significant difference in soil compaction. In a 5-10 cm layer, undersown species significantly increased the soil compaction – in the case of white clover by 67.1%, and in the case of serradella by 25.4%. Also in the plots under the mixture of rye varieties it was observed that soil compaction increased as much as by 48.7% in comparison with the plots where the pure rye was sown. The implementation of white clover as well as serradella in a 10-15 cm layer increased soil compactness by 34.3% and 18 % respectively and soil compaction in the plots under cultivar mixture was significantly higher than the one observed in the pure stand by 18%. In the deepest layer, white clover increased the soil compaction by 22.6% and serradella by 10.9%.

Table 5. Soil compaction, MPa
Tabela 5. Zwięzłość gleby, MPa

Undersown species Gatunek wsiewki	Year – Rok								
	2012			2013			2014		
	method of rye sowing – sposób siewu żyta								
	pure czysty	mixed miesz.	mean średnia	pure czysty	mixed miesz.	mean średnia	pure czysty	mixed miesz.	mean średnia
	layer – warstwa 0-5 cm			layer – warstwa 0-5 cm			layer – warstwa 0-5 cm		
No undersown – Brak wsiewki	1.39	1.49	1.44	1.87	1.83	1.85	1.36	1.51	1.43
White clover – Koniczyna biała	1.29	1.24	1.26	1.34	1.33	1.34	3.35	3.09	3.21
Serradella – Seradela	1.32	1.29	1.30	1.40	1.37	1.39	2.56	2.82	2.70
Mean – Średnia	1.34	1.34		1.54	1.51		2.42	2.48	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla									
method of sowing – sposobu siewu		ns – ni			ns – ni			ns – ni	
undersown species – wsiewki		0.08			0.29			0.31	
interaction – interakcji		ns – ni			ns – ni			ns – ni	
	layer – warstwa 5-10 cm			layer – warstwa 5-10 cm			layer – warstwa 5-10 cm		
No undersown – Brak wsiewki	3.00	3.23	3.12	3.38	3.48	3.43	2.88	5.65	4.26
White clover – Koniczyna biała	2.17	2.13	2.15	2.66	2.57	2.61	6.12	8.11	7.12
Serradella – Seradela	2.42	2.42	2.42	2.89	2.82	2.85	4.45	6.22	5.34
Mean – Średnia	2.54	2.60		2.97	2.95		4.48	6.66	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
method of sowing – sposobu siewu		ns – ni			ns – ni			0.68	
undersown species – wsiewki		0.15			0.32			1.08	
interaction – interakcji		ns – ni			ns – ni			ns – ni	
	layer – warstwa 10-15 cm			layer – warstwa 10-15 cm			layer – warstwa 10-15 cm		
No undersown – Brak wsiewki	4.71	4.73	4.72	4.95	4.88	4.92	5.08	6.07	5.57
White clover – Koniczyna biała	3.96	4.00	3.98	4.52	4.44	4.48	6.70	8.27	7.48
Serradella – Seradela	4.25	4.08	4.17	4.69	4.83	4.76	6.23	6.91	6.57
Mean – Średnia	4.31	4.27		4.72	4.72		6.00	7.08	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
method of sowing – sposobu siewu		ns – ni			ns – ni			0.87	
undersown species – wsiewki		0.25			0.29			0.66	
interaction – interakcji		ns – ni			ns – ni			ns – ni	
	layer – warstwa 15-20 cm			layer – warstwa 15-20 cm			layer – warstwa 15-20 cm		
No undersown – Brak wsiewki	5.86	5.62	5.74	6.10	5.80	5.95	5.86	6.60	6.23
White clover – Koniczyna biała	5.12	5.12	5.12	5.21	5.20	5.21	7.32	7.95	7.64
Serradella – Seradela	5.24	5.24	5.24	5.47	5.63	5.55	6.49	7.32	6.91
Mean – Średnia	5.41	5.32		5.59	5.54		6.56	7.29	
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
method of sowing – sposobu siewu		ns – ni			0.05			ns – ni	
undersown species – wsiewki		0.17			0.29			0.37	
interaction – interakcji		ns – ni			ns – ni			ns – ni	

ns – ni – not significant difference – różnice nieistotne
miesz. – mieszanina

DISCUSSION

One of the most important considerations in growing cover crops is their impact on soil moisture. In literature the opinions on this issue are divided. They show that a cover catch crop affects water relations in soil to a certain extent. Largely, it depends on

precipitation, the type of soil but also on crop species, the type of cover catch crop and species sown in it [Kuś and Jończyk 2000, Wojciechowski 2004, Jaskulski and Jaskulska 2004]. In general, during the years poor in precipitation the cover catch crops make soil dry out. In the balanced years or those abundant in rainfall they remain unaffected or just slightly improve its moisture content. [Parylak 1999, Wacławowicz and Parylak 2004]. The majority of research concerning the physical properties of soil was done mainly with the use of stubble catch crops.

In the experiment the implementation of undersown species just in one year significantly decreased soil moisture. It was a year with the least favourable weather conditions for the undersown species growth. In the other years the presence of undersown species did not affect soil moisture. Tendziagolska [2010] observed the significant decrease in the amount of water stored in soil under oats cultivation together with undersown species of white clover in comparison with the oats pure stand. Probably it was connected with the competition for water between the two crops. In the research of Wanic *et al*. [2013], the implementation of undersown species of ryegrass and red clover in the cultivation of spring barley resulted in more favourable moisture conditions only in the more shallow 0-10 cm layer. In the deeper one, they did not affect the moisture conditions.

According to Baldwin and Creamer [2007] cover crops in an organic farm increase soil porosity and decrease soil bulk density to promote the root growth. Pierce *et al*. [1983] and Fulton *et al*. [1996] reported that bulk density over 1.8 g cm^{-3} restricts the plant root growth in sandy soils, and the values around 1.7 g cm^{-3} could adversely affect plant growth. In our studies the values of bulk density were in the range 1.59-1.76 g·cm^{-3}.

According to Baranowski [1980], bulk density is affected differently and depends on soil and the weather conditions, the level of fertilization, crop species and the direct outcome of the changes in bulk density are the changes in total porosity. In our research the significant differences in bulk density under the research factors were not observed. What was noticed was a slight decrease of this parameter after the implementation of undersown species of pasture legumes into agricultural practices. Similar results were obtained by Wojciechowski [2009] who showed the slight decrease in the bulk density under stubble catch crop including pasture legumes.

Soil porosity examined in the first two years of the experiment was significantly affected by the presence of clover and serradella, when their implementation increased both total and capillary porosity, especially in a 5-10 cm layer. In the last year of the research, the direction of the changes in the deeper layer under variety mixture continued, although it was not mathematically proved. Wojciechowski [2009] also obtained the same results showing the beneficial effect of ploughed down stubble catch crops on total and capillary porosity.

Fischler *et al*. (1999) found that there were sustained improvements in soil physical properties due to the crotalaria green manure combined into the maize-bean cropping system. They noted a small decrease in bulk densities and the increase in porosity. Bulk density and porosity affected by undersown species were shown in the decreased soil compaction (in the first two years of the research). Hartwin and Ammon [2002] and Latif *et al*. [1992] confirm the reduction of soil compaction in undersown corn with clover (*Trifolium* spp.). Hoorman *et al*. [2009] also show the beneficial effect of numerous species cultivated as cover catch crops on the reduction of soil compaction. However, in the third year of the research the implementation of pasture legumes into rye resulted in the increase in soil compaction, which was most probably connected

with dried out soil under unfavourable weather conditions (mainly temperatures higher than average). The amount of water in soil is directly correlated to its potential for compaction. Soil moisture affects the degree of soil compaction as it can lubricate, as well as provide cohesion to soil particles [Adams and Froehlich 1981]. Tendziagolska [2010] by cultivating oats under white clover, showed the significant increase in soil compaction below the depth of 5 cm, on average, about over 30% in comparison with the classic oats cultivation as well as the decrease in soil moisture at the same time. In the research of Wojciechowski and Sowiński [2002] higher soil compaction was also proved after sowing of wheat into white clover mulch particularly in the season with poorer precipitations.

CONCLUSIONS

Under normal distribution of precipitation, but in the high annual temperatures, the presence of undersown species in rye significantly affected the decrease of soil moisture and the increase in soil compaction. In the remaining years, when more optimal distribution of precipitation and temperatures was noticed, the implementation of white clover and serradella did not affect soil moisture and soil compaction was significantly lower under both undersown species. The implementation of white clover and serradella into agricultural practices of rye did not affect bulk density, although its slight increase was observed. The presence of white clover and serradella in the rye stand significantly increased total and capillary porosity in a 5-10 cm layer. The similar tendency, although statistically not proved, was observed in a 15-20 cm layer.

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KSZTAŁTOWANIE WYBRANYCH WŁAŚCIWOŚCI FIZYCZNYCH GLEBY POD WPŁYWEM WSIEWEK MIĘDZYPLONOWYCH W UPRAWIE EKOLOGICZNEGO ŻYTA

Streszczenie. Dwuczynnikowe doświadczenie założono w latach 2011-2014 metodą losowanych podbloków. Celem badań była ocena wpływu wsiewek koniczyny białej oraz seradeli, uprawianych w życie jednoodmianowym lub mieszaninie trójodmianowej, na wybrane właściwości fizyczne gleby. W warunkach normalnego rozkładu opadów, ale

przy bardzo wysokiej temperaturze mierzonej na przestrzeni lat, wsiewki wyraźnie zmniejszyły wilgotność gleby oraz zwiększyły jej zwięzłość. W pozostałych latach, o bardziej optymalnym rozkładzie opadów i temperatury powietrza, wprowadzenie do łanu żyta roślin bobowatych nie różnicowało stanu uwilgotnienia gleby, jak również znacząco zmniejszyło jej zwięzłość. Obecność wsiewek w łanie żyta nie wpłynęła na gęstość objętościową, choć obserwowano jej nieznaczne zwiększenie. Koniczyna biała oraz seradela w życie istotnie zwiększyły ogólną i kapilarną porowatość gleby w warstwie 5-10 cm. Ta tendencja utrzymała się także w warstwie 15-20 cm.

Słowa kluczowe: gęstość objętościowa, koniczyna biała, porowatość, seradela, wilgotność gleby, zwięzłość

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