Acta Agroph., 2016, 23(4), 661-680

INFLUENCE OF SOIL COMPACTION AND TILLAGE METHODS ON PENETRATION RESISTANCE OF SOIL AND YIELDS IN THE CROP ROTATION SYSTEM

Krzysztof Orzech[1], *Maria Wanic*[1], *Dariusz Załuski*[2], *Arkadiusz Stępień*[1]

[1]Department of Agroecosystems, University of Warmia and Mazury in Olsztyn
[2]Department of Plant Breeding and Seed Production, University of Warmia and Mazury in Olsztyn
Plac Łódzki 3, 10-900 Olsztyn, Poland
e-mail: krzysztof.orzech@uwm.edu.pl

A b s t r a c t. Changes in soil penetration resistance and yields of winter rapeseed, winter wheat and spring barley cultivated in the 3-year rotation system under the influence of soil compaction and four tillage methods were evaluated in a field experiment conducted in 2009-2012. During the stage of full emergence of winter rapeseed, at the depth of 0-10 and 10-20 cm (lots without compaction) after U-2 cultivation (subsoiler 40 cm, disk cultivator, harrowing, cultivating, sowing ploughing 20 cm), the resistance of the soil decreased significantly as compared to the plough cultivation (control lot). At the level of 20-30 cm, after conventional cultivation, significantly lower compaction of the soil was found compared to the other cultivation variants. On the compacted lots, the opposite situation was found. During the full blossom stage, in the lots without compaction, tillage increased the soil compaction significantly within the studied soil levels, compared to the reduced tillage variants. On the other hand, at the depth of 20-30 cm (lots with compaction), regardless of the reduced tillage variant, significantly higher compaction of the soil, as compared to the plough cultivation, was recorded. After rapeseed harvest, at the depth of 10 cm (lots without compaction), after U-2 cultivation, almost 2-fold increase in the value of the analysed characteristic was recorded as compared to the plough cultivation. During the wheat stem elongation stage, on the lots without and with compaction, the highest soil compaction was found at the depth of 20-30 cm after U-3 cultivation. In the lots without compacting, during the heading, the application of the ripper (U-2 cultivation) significantly decreased the compaction of soil down to 10 cm. In the 20-30 cm layer (lots with compaction), soil resistance increased, assuming the highest values after subsoiler and single ploughing. After the harvest of crops from the lots without compaction, an increase of soil compaction, as compared to the plough cultivation, was recorded after U-2 cultivation at the depth of up to 10 cm and in the 10-20 cm layer after the application of subsoiler and single ploughing. The degree of compaction and the method of soil cultivation diversified significantly the yields of the analysed cereal. Following spring barley harvest, in the lots without compaction, significantly higher soil resistance was found after applying full plough cultivation compared to the lots with compaction (depth 10-20 cm). Similar outcomes were obtained at the levels of 0-10 and

10-20 cm after U-2 cultivation (skimming, cultivator, harrow + pre-winter tillage to 25 cm) and at the depth of 20-30 cm after the application of the cultivator and performance of pre-winter tillage to the depth of 25 cm (U-3 cultivation). On the compacted lots, as compared to the lots that were not compacted, a significantly higher yield of winter rapeseed was obtained following U-3 cultivation. Post-harvest cultivation using the subsoiler and pre-sowing cultivation by single ploughing decreased the winter wheat yield the most as compared to the traditional cultivation. The yield of grain from lots with soil compaction, compared to lots without compaction, was significantly higher. In the case of lots with compaction, the application of skimming, cultivator treatment and harrowing of the field after harvest of the forecrop and performance of pre-winter tillage to the depth of 25 cm (U-2 cultivation) increased spring barley yield significantly compared to the conventional cultivation.

Keywords: soil packing, soil tillage, crop yield, winter wheat, spring barley, winter oilseed rape, soil compaction

INTRODUCTION

The plough cultivation system, in addition to numerous advantages, has numerous shortcomings. One of these is soil density increase resulting from compacting (Arvidsson and Håkansson 1996), a problem of increasing importance during these times of progressing intensification and mechanisation of field works. The increasing numbers of tractors and heavy agricultural equipment operating in fields cause compaction of the soil system. This leads to, among other things, increased compactness (Marks and Buczyński 2002), which hinders plant roots development, water and air conductivity, as well as absorption of mineral compounds. It also limits thegrowth of plants, leading to a decrease of their yields (Boydas and Turgut 2007, Camara *et al*. 2003, Małecka *et al*. 2012).

One way to reduce the negative effects of soil compaction is the introduction of reduced tillage systems,designed, among other things, to reduce the number of treatments and the intensity of soil loosening, or even to completely eliminate them (Biskupski *et al*. 2009, Małecka *et al*. 2004, Małecka *et al*. 2014, Wesołowski and Cierpiała 2011). Such a treatment combines soil protecting measures and allows maintenance of the environmental values of the agricultural ecosystems (Jaskulski *et al*. 2012, Kuc 2014).

Given the above, the research hypothesis was formulated that soil compaction contributed to soil penetration resistance increase and that the appropriate soil tillage method might be a factor mitigating that process. That hypothesis was verified based on the field experiment. It aimed at the determination of the influence of compaction and different cultivation methods on soil compaction and yields of crops cultivated in the rotation system sequence – winter rapeseed, winter wheat and spring barley.

MATERIAL AND METHODS

The paper is based on the results of tests obtained in a static, two-factor field experiment conducted at the Production-Experimental Enterprise in Bałcyny (53°36'N 19°51'E) which is the experimental base of the University of Warmia and Mazury in Olsztyn (Poland). The experiment was set up according to the randomised block in four replicates. The number of lots was 30 and the area of each lot was 30 m^2.

The experiment was conducted on a typical medium grey-brown podzolic soil developed from sandy clay. In the layer of 0-20 cm, it contained from 10 to 10.7 g $kg^{-1}$of organic carbon. Its reaction was acid to mildly acid (pH_{KCl} 5.4-5.6), It was characterised by content of phosphorus from 74.0 to 82.1 mgkg (moderate abundance), potassium from 98.2 to 160.1 mgkg (low to moderate abundance) and magnesium from 36.1to 39.0 mgkg (low). In its particle size composition the analysed soil contained fractions with diameters of< 0.002 (3.7%), 0.002-0.050 (35.1%) and 0.050-1.00 (61.2%).

In the experiment conducted in 2009-2012, four soil cultivation methods applied in the three-field rotation system of winter rapeseed (cv. Mendel),winter wheat (cv. Ludwig) and spring barley (cv. Justina) were compared. The experimental factors were: I – level of pre-sowing soil compaction (A – control lot without compaction, B – a lot with soil compaction after harvest of the forecrop – passage of the tractor + trailer unit ca. 6 tonnes in weight track by track), II – 4 tillage methods: U-1 (conventional tillage), U-2, U-3, U-4 (reduced tillage compared with U-1) (Table 1).

Crops were sown at the optimal times in the following quantities: winter rapeseed 5 $kgha^{-1}$, winter wheat 205 $kgha^{-1}$and spring barley 170 $kgha^{-1}$. In the experiment, only mineral fertilisation was applied at the following doses of the pure component ($kgha^{-1}$): winter rapeseed N – 180, P – 35 and K – 100, winter wheat N – 50; P – 35 and K – 100, spring barley N – 80, P – 30 i K – 83. Plant protection agents were applied depending on the invasiveness of agricultural pests. Harvest was conducted at the stage of full grain ripeness (BBCH 89-92), and in the case of the winter rapeseed, at full ripeness of the seeds (BBCH 86-89).

Soil penetration resistance measured mechanical probe diameter cone 11 mm and an apex angle of 63 degrees in the 0-30 cm soil layer. Measurements were made in each plot in four areas of solid areas, including volumes 0-10, 10-20 and 20-30 cm. Determinations for the cereals were made during the stages of stem elongation (BBCH 31), heading (BBCH 56-59) and after harvest, while in the case of winter rapeseed – during the stages of full emergence (BBCH 10-11), full blossom (BBCH 65) and full ripeness of seeds (BBCH 86-89).

The unit yield of seeds and grain was also determined (kg from lot). The results were converted to the yield per 1 ha.

Table 1. Tillage systems applied in crop rotation in 2009-2012

Tillage	U-1*	U-2	U-3	U-4
		Winter oilseed rape		
After harvest	skimming10 cm + harrowing	subsoiler (40 cm) + disk cultivator + harrowing + cultivating	skimming10 cm + harrowing	–
Before sowing	sowing ploughing 20 cm	sowing ploughing 20 cm	–	single ploughing 30 cm
		Winter wheat		
After harvest	skimming10 cm +harrowing	rotary cultivator	disk cultivator + harrowing + cultivating	subsoiler (40 cm)
Before sowing	sowing ploughing 20 cm	sowing ploughing 25 cm	sowing ploughing 20 cm	single ploughing 30 cm
		Spring barley		
After harvest	skimming10 cm +harrowing	skimming 10 cm + harrowing + cultivating	cultivator	–
Before sowing	winter ploughing 30 cm	winter ploughing 25 cm	winter ploughing 25-30 cm	single ploughing 30 cm

*U-1 – conventional tillage (control treatment)

During the period of autumn vegetation of winter rapeseed (from August to October 2009-2012), the sum of precipitations was lower by ca. 81% than the multiyear average (Table 2).

Table 2. Temperature and precipitations during vegetation of the cultivated crops

Years	Months								
	VIII	IX	X	III	IV	V	VI	VII	VIII
				Mean air temperature (°C)					
2009/2010	18.1	14.6	8.6	3.5	8.4	13.9	15.2	19.0	17.9
2010/2011	18.5	14.7	5.9	2.1	7.9	12.0	15.7	20.8	19.3
2012	0	0	0	2.0	9.7	13.6	17.5	18.0	18.1
1962-2002	16.8	12.6	8.1	1.4	7.0	12.5	15.8	17.2	16.8
				Precipitation (mm)					
2009/2010	83.6	38.9	29.9	21.3	44.7	42.5	107.2	112.2	75.2
2010/2011	25.7	15.6	58.5	23.8	9.4	105.5	73.7	87.8	99.3
2012	0	0	0	8.6	33.7	41.5	56.2	171.9	83.6
1962-2002	75.2	59.1	54.0	28.8	35.4	57.6	69.5	81.6	25.7

During the spring-summer vegetation, the average air temperature (13.0°C) and the sum of precipitations (403.1 mm) exceeded the average values from the multiyear period. In April, the recorded precipitations were higher by 9.3 mm than the multiyear average. In May, the period of flowering and pod formation, there was only 42.5 mm of rain, while June and July were very wet with the sum of precipitations being higher by 37.7 and 30.6 mm, respectively, compared to the average multiyear values recorded for the area of Bałcyny.

During the vegetation period of winter wheat, from September until August, the average air temperature was at a level similar to the recorded multiyear values for the area of Bałcyny while the sum of precipitations was higher by 61.9 mm from those values (Tab. 2). March 2011 was warm (2.1°C), and April was very dry (9.4 mm). In May, the precipitations were higher by 47.9 mm than the multiyear average, while in June and July the air temperature exceeded the average values from multiyear period by almost 21%.

During the year of spring barley cultivation, from March until the end of June, a drought occurred. In May and June, the sum of precipitations, compared to the multiyear averages, was lower by 16.1 and 13.3 mm, respectively. During those months, the air temperatures were higher by 1.1 and 1.7°C, respectively, than the recorded multiyear averages. On the other hand, July was extremely humid with the sum of precipitations more than twice higher than the multiyear average.

The results obtained were processed statistically. The significance of differences between the reduced tillage methods and conventional tillage were evaluated by means of the Dunnett test at the significance level $\alpha = 0.05$, while the significance of differences between mean values for the objects with compaction and without compaction were evaluated by means of Student's t-test for independent samples. The correlations between the test crops yields and soil compaction were also computed using the Spearman rank coefficient. The computations were performed using the Statistica software package.

RESULTS

The soil cultivation method diversified soil density at some levels and some development stages of winter rapeseed (Tab. 3). At full emergence, on lots without packing, simplified cultivation U-2 (subsoiler, disc harrow, cultivator, harrowing, sowing tillage 20 cm) significantly decreased the resistance of soil at depths of 0-10 and 10-20 cm, compared to the conventional cultivation (control lot). Decrease in penetration resistance was also found in the soil layer of 20-30 cm after the application of all the reduced tillage methods (on average by 0,18 MPa). On compacted lots, the opposite situation was recorded. All the reduced tillage systems evaluated resulted in a significant increase (almost 1.5 fold) in penetration resistance, compared to the conventional tillage.

Table 3. Effect of tillage systems on soil penetration resistance (MPa) under winter rapeseed

Degree of soil packing	Tillage methods				
	U-1	U-2	U-3	U-4	Mean
full emergence / soil layer					
0-10 cm					
A[1]	0.57	0.48*	0.50	0.52	0.52
B[2]	0.66	0.59	0.74	0.63	0.66
10-20 cm					
A	0.76	0.61*	0.65	0.69	0.68
B	0.69	0.73	0.81	0.66	0.72
20-30 cm					
A	0.83	0.66**	0.61**	0.69*	0.70
B	0.63	0.88**	0.91**	0.84**	0.82
full blossom stage / soil layer					
0-10 cm					
A	0.60	0.48**	0.48**	0.49**	0.51
B	0.66	0.54	0.70	0.60	0.63
10-20 cm					
A	0.73	0.52*	0.55*	0.56*	0.59
B	0.63	0.65	0.71	0.63	0.66
20-30 cm					
A	0.79	0.59*	0.55**	0.64	0.64
B	0.56	0.81*	0.88*	0.80*	0.76
full ripeness of seeds / soil layer					
0-10 cm					
A	0.58	0.67*	0.60	0.64	0.62
B	0.48	0.56	0.50	0.57	0.53
10-20 cm					
A	0.68	0.67	0.66	0.61	0.66
B	0.61	0.82	0.60	0.72	0.69
20-30 cm					
A	0.79	0.69	0.88	0.67	0.76
B	0.64	0.79	0.70	0.90	0.76

Explanations: see Table 1; A[1] – without compaction; B[2] – with compaction; * – significance at $p < 0.05$; ** – significance at $p < 0.01$

Following the application of conventional tillage, during the full emergence phase on the lots without compaction, in the levels of 0-10, 10-20 and 20-30 cm, a significant increase of soil penetration resistance was found in comparison to the reduced tillage variants. On lots with compaction, the evaluated soil cultivation methods did not alter the evaluated parameter significantly at depths of 0-10 and 10-20 cm, as opposed to the 20-30 cm layer in which significantly higher penetration resistance was found after the application of reduced tillage treatments (by almost 50%).

During the rapeseed ripeness phase, significant changes in soil compaction occurred after the application of the U-2 reduced tillage system in the 0-10 cm soil layer of the lot without compaction. That cultivation variant contributed to an increase in soil compaction, compared to the conventional tillage system (by 15.5%).

Table 4. Comparison of penetration resistance in objects without compaction and with compaction soil in examined the levels and data development stages of winter rapeseed with t-Student test

Tillage methods	Development stage	Soil layer depth (cm)	Mean – without soil compaction (MPa)	Mean with soil compaction (MPa)	p
U-1	full emergence	0-10	0.57	0.66	0.506
		10-20	0.76	0.69	0.118
		20-30	0.83	0.63	0.001
	full blossom stage	0-10	0.60	0.66	0.651
		10-20	0.73	0.63	0.235
		20-30	0.79	0.56	0.002
	full ripeness of seeds	0-10	0.58	0.48	0.048
		10-20	0.68	0.61	0.621
		20-30	0.79	0.64	0.290
U-2	full emergence	0-10	0.48	0.59	0.007
		10-20	0.61	0.73	0.045
		20-30	0.66	0.88	0.001
	full blossom stage	0-10	0.48	0.54	0.114
		10-20	0.52	0.65	0.130
		20-30	0.59	0.81	0.111
	full ripeness of seeds	0-10	0.67	0.56	0.000
		10-20	0.67	0.82	0.186
		20-30	0.69	0.79	0.540
U-3	full emergence	0-10	0.50	0.74	0.003
		10-20	0.65	0.81	0.164
		20-30	0.61	0.91	0.003
	full blossom stage	0-10	0.48	0.70	0.008
		10-20	0.55	0.71	0.060
		20-30	0.55	0.88	0.000
	full ripeness of seeds	0-10	0.60	0.50	0.156
		10-20	0.66	0.60	0.623
		20-30	0.88	0.70	0.493
U-4	full emergence	0-10	0.52	0.63	0.042
		10-20	0.69	0.66	0.500
		20-30	0.69	0.84	0.123
	full blossom stage	0-10	0.49	0.60	0.139
		10-20	0.56	0.63	0.335
		20-30	0.64	0.80	0.252
	full ripeness of seeds	0-10	0.64	0.57	0.478
		10-20	0.61	0.72	0.573
		20-30	0.67	0.90	0.150

Explanation see Table 1; value of probability of Student's t-test (significance $p < 0.05$)

In some tested soil levels and winter rapeseed development stages significant differences in soil compactness were found between the lots with compaction and without compaction (Tab. 4). On lots without compaction, during the full emergence and full blossom phases, significantly higher resistance of soil was found at the depth of 20-30 cm (by 31.7 and 41.1%) after the application of plough cultivation compared to the compacted lots. On the other hand, the reduced tillage systems U-2 and U-3 applied to lots with compaction increased the soil density significantly during full emergence within the entire soil profile tested (0-30 cm). An exception was the 10-20 cm layer after U-3 cultivation, when only the tendency for its increase was recorded. During that period, similar outcomes were obtained after single ploughing (U-4 cultivation) down to10 cm. During full blossom stage of rapeseed, the soil at the depth 0-10 and 20-30 cm was characterised by significantly higher compaction after the application of compaction combined with reduced tillage U-3 (by 60%). Furthermore, at the end of vegetation, an increase in the value of that parameter was recorded in its surface layer on the lot without compaction after conventional cultivation (by 20.8%).

The soil cultivation method differentiated soil compaction at the depth of 20-30 cm during the stem elongation of winter wheat (Tab. 5). Both lots with and without compaction displayed significantly higher soil resistance (more than 3-fold and almost 2-fold) after U-3 cultivation than after conventional cultivation. A significant increase in soil compaction was also found on the U-2 lot with compaction and U-4 without compaction (by 69.2 and 228.0%, respectively).

During the heading phase,a significant decrease in soil compaction (more than 2-fold) was found after the ripper and sowing tillage (U-2), compared to conventional cultivation on non-compacted lots in the soil layer down to10 cm. At the level of 10-20 cm, on lots without compaction, a significant increase in soil compaction, compared to the plough cultivation, occurred in U-4 cultivation (subsoiler and single ploughing). On lots with compaction, regardless of the reduced tillage variant applied, a significant decrease of soil compaction was found in that layer (on average by ca. 50%). At the depth of 20-30 cm, compaction combined with the application of disc harrowing, cultivator treatment and harrowing in the group of post-harvest cultivation treatments (U-3), decreased soil compaction by almost 2-fold. After the application of subsoiler with single ploughing (U-4), the opposite situation was found – it increased significantly (by ca. 41%) compared to the plough cultivation.

After wheat harvest, from 0-10 cm on lots without compaction, the application of the ripper and single ploughing (U-2) produced a significant (almost 2-fold) increase in soil compaction compared to the plough cultivation. An almost 1.5-fold soil density increase was also found in the 10-20 cm layer after the application of the subsoiler and single ploughing (U-4).

Table 5. Effect of tillage systems on soil penetration resistance (MPa) under winter wheat

Degree of soil packing	Tillage methods				
	U-1	U-2	U-3	U-4	Mean
		stem elongation / soil layer			
		0-10 cm			
A[1]	0.11	0.13	0.13	0.13	0.13
B[2]	0.12	0.12	0.12	0.11	0.12
		10-20 cm			
A	0.14	0.24	0.27	0.25	0.23
B	0.21	0.25	0.22	0.15	0.21
		20-30 cm			
A	0.25	0.44	0.81**	0.57**	0.50
B	0.39	0.66**	0.77**	0.41	0.56
		heading phase /soil layer			
		0-10 cm			
A	0.27	0.12*	0.14	0.17	0.18
B	0.12	0.12	0.12	0.14	0.13
		10-20 cm			
A	0.22	0.20	0.24	0.33*	0.25
B	0.38	0.19**	0.16**	0.23**	0.24
		20-30 cm			
A	0.97	0.66	0.65	0.79	0.77
B	0.78	0.76	0.43**	1.10**	0.77
		after harvest / soil layer			
		0-10 cm			
A	0.49	0.88**	0.28	0.75	0.61
B	0.55	0.70	0.51	0.60	0.59
		10-20 cm			
A	1.27	1.41	1.48	1.82**	1.50
B	1.49	1.51	1.35	1.53	1.47
		20-30 cm			
A	1.71	2.07	2.18	2.19	2.04
B	2.01	2.02	1.86	2.06	1.99

Explanations: see Table 1; A[1] – without packing; B[2] – with packing; * – significance at $p < 0.05$; ** – significance at $p < 0.01$

Comparison of soil compaction between the lots with and without compaction showed a significant diversification of the value of the analysed characteristic during chosen development stages of wheat (Tab. 6). During the stem elongation phase, on compacted lots, compared to the lots without compaction (depths of 10-20 and 20-30 cm), significantly higher soil resistance was found after the application of plough cultivation. Similar results were obtained at the level of 10-20 cm during the heading phase. On lots with U-2 cultivation without compaction, a significant decrease in soil resistance was found at the depth of 20-30 cm during the stem elongation phase and after harvest, while a significant increase in the value of analysed characteristic was recorded in the 0-10 cm layer. U-3 cultivation offered similar outcomes during the heading phase. On treated lots without compaction, significantly higher soil compaction occurred in the 10-20 cm layer and at the depth of 20-30 cm after the harvest of the crop. On the U-4 lot, during the stem elongation phase, significantly lower soil compaction was found on lots with compaction in the 20-30 cm layer and during the heading phase, as well as after wheat harvest in the 10-20 cm layer.

Table 6. Comparison of penetration resistance in objects without compaction and with compaction soil in examined the levels and data development stages of winter wheat with t-Student test

Tillage methods	Development stage	Soil layer depth (cm)	Mean-without soil compaction (MPa)	Mean– with soil compaction (MPa)	p
U-1	stem elongation	0-10	0.113	0.123	0.304
		10-20	0.138	0.208	0.032
		20-30	0.253	0.385	0.036
	heading phase	0-10	0.268	0.123	0.063
		10-20	0.223	0.378	0.004
		20-30	0.965	0.783	0.068
	after harvest	0-10	0.485	0.550	0.363
		10-20	1.273	1.490	0.056
		20-30	1.705	2.013	0.450
U-2	stem elongation	0-10	0.125	0.123	0.766
		10-20	0.238	0.253	0.768
		20-30	0.443	0.655	0.004
	heading phase	0-10	0.118	0.123	0.654
		10-20	0.198	0.193	0.900
		20-30	0.663	0.758	0.371
	after harvest	0-10	0.875	0.703	0.040
		10-20	1.408	1.513	0.510
		20-30	2.073	2.015	0.635
U-3	stem elongation	0-10	0.128	0.120	0.620
		10-20	0.273	0.223	0.543
		20-30	0.808	0.768	0.604
	heading phase	0-10	0.143	1.123	0.456
		10-20	0.240	0.163	0.002
		20-30	0.648	0.425	0.168
	after harvest	0-10	0.283	0.508	0.015
		10-20	1.480	1.350	0.260
		20-30	2.183	1.858	0.039
U-4	stem elongation	0-10	0.125	0.110	0.059
		10-20	0.253	1.153	0.048
		20-30	0.565	0.410	0.039
	heading phase	0-10	0.173	0.143	0.066
		10-20	0.325	0.233	0.012
		20-30	0.793	1.100	0.064
	after harvest	0-10	0.750	0.598	0.247
		10-20	1.820	1.530	0.020
		20-30	2.188	2.060	0.099

Explanation see table 1; p – value of the probability of Student's t-test (significance $p < 0.05$)

In the soil under spring barley during the stem elongation phase, significant changes in soil density were recorded only on the lots without compaction after the application of the U-2 cultivation (skimming, cultivator, harrow + pre-winter tillage; 25 cm) (Table 7).

Table 7. Effect of tillage systems on soil penetration resistance (MPa) under spring barley

Degree of soil packing	Tillage methods				
	U-1	U-2	U-3	U-4	Mean
	stem elongation / soil layer				
	0-10 cm				
A[1]	0.47	0.92*	0.82	0.76	0.74
B[2]	0.45	0.57	0.49	0.70	0.55
	10-20 cm				
A	1.10	1.18	0.99	1.17	1.11
B	0.61	0.74	0.75	0.98	0.77
	20-30 cm				
A	1.27	1.36	1.31	1.34	1.32
B	1.22	1.21	1.15	1.22	1.20
	heading phase /soil layer				
	0-10 cm				
A	0.42	0.53	0.75**	0.47	0.54
B	0.41	0.45	0.63**	0.47	0.49
	10-20 cm				
A	0.54	0.74	0.72	0.75	0.69
B	0.49	0.49	0.74**	0.67*	0.60
	20-30 cm				
A	0.75	1.12	0.87	0.95	0.92
B	0.61	0.74	0.85*	0.82*	0.76
	after harvest / soil layer				
	0-10 cm				
A	0.44	1.10**	0.88*	0.93*	0.84
B	0.47	0.47	0.63**	0.67**	0.56
	10-20 cm				
A	0.56	1.31**	0.98**	0.98**	0.96
B	0.46	0.49	0.60**	0.64**	0.55
	20-30 cm				
A	0.81	1.42**	1.05*	1.32**	1.15
B	0.49	0.59**	0.66**	0.74**	0.62

Explanations: see Table 1; A[1] – without compaction; B[2] – with compaction; * – significance at $p < 0.05$; ** – significance at $p < 0.01$

In this case the increase in soil compaction (by almost 2-fold) occurred at the depth of 0-10 cm compared to the conventional cultivation.

During barley heading stage, on both lots (without and with compaction), in the 0-10 cm soil layer an increase in the value of the analysed characteristic occurred after U-3 cultivation (cultivator + pre-winter tillage 25 cm) compared to the conventional cultivation, by 0.33 and 0.22 MPa. The identical cultivation method increased the soil resistance the most at the depths of 10-20 and 20-30 cm compared to the plough cultivation on lots with compaction. Compaction contributed also to a significant increase in soil density after the application of U-4 cultivation (single ploughing).

After harvest of spring barley, significantly higher compaction was recorded after all of the applied variants of cultivation in three analysed soil layers on lots without compaction. The largest increase (by 2.5-fold) occurred in the layers of 0-10 and 10-20 cm (2.5-fold and 2.3 fold, respectively). Similar outcomes were obtained on the compacted lots after applying the U-2 cultivation, except in the layers of 0-10 and 10-20 cm.

The soil cultivation method on lots with and without compaction during some periods and in certain soil layers, the soil cultivation method on lots with and without compaction significantly diversified soil compaction under spring barley (Tab. 8). Increased compaction was found at the layer of 10-20 cm after the application of the U-1 cultivation after harvest, after the U-2 cultivation (each layer). Following the U-3, it was recorded in the layer of 0-10 cm during the stem elongation phase and 20-30 cm after harvest, as well as the U-4 at the level of 10-20 and 20-30 cm after harvest.

The soil compaction level also diversified the yield of winter rapeseed (Tab. 9). On compacted lots, compared to lots without The soil cultivation method on lots with and without compaction, the yield was significantly higher after application of the U-3 cultivation (by 30.1%).The cultivation method also influenced the value of the investigated characteristic significantly. Following the U-3 cultivation on both lots, with and without compaction (skimming 10 cm + harrowing 10 cm), a significantly lower yield of the crop was recorded compared to the plough cultivation, by 31.6 and 21.3%, respectively

Winter wheat, regardless of soil compaction, produced significantly lower yields after the application of the U-4 reduced cultivation (subsoiler, single ploughing). The difference in the yield compared to the conventional cultivation (U-1) was 13.9% in the lots without compaction and 7.3% in the lots with compaction The application of the subsoiler and single ploughing, nevertheless, increased the yield of wheat significantly, compared to the lots without soil compaction. The application of skimming, cultivator treatment and harrowing of the field after harvest of the forecrop and performance of pre-winter tillage to the depth of 25 cm (U-2 cultivation) on lots with compaction significantly increased (by 10.8%) the yield of spring barley compared to the conventional cultivation.

A similar situation was found on the lots without compaction, but the differences observed were not confirmed statistically.

Table 8. Comparison of penetration resistance in objects without compaction and with compaction soil in examined the levels and data development stages of spring barley with t-Student test

Tillage methods	Development stage	Soil layer depth (cm)	Mean – without soil packing (MPa)	Mean – with soil packing (MPa)	P
U-1	stem elongation	0-10	0.47	0.45	0.793
		10-20	1.10	0.61	0.098
		20-30	1.27	1.22	0.689
	heading phase	0-10	0.42	0.41	0.773
		10-20	0.54	0.49	0.408
		20-30	0.75	0.61	0.134
	after harvest	0-10	0.44	0.47	0.466
		10-20	0.56	0.46	0.016
		20-30	0.81	0.49	0.000
U-2	stem elongation	0-10	0.92	0.57	0.179
		10-20	1.18	0.74	0.152
		20-30	1.36	1.21	0.519
	heading phase	0-10	0.53	0.45	0.131
		10-20	0.74	0.49	0.061
		20-30	1.12	0.74	0.143
	after harvest	0-10	1.10	0.47	0.016
		10-20	1.31	0.49	0.004
		20-30	1.42	0.59	0.000
U-3	stem elongation	0-10	0.82	0.49	0.046
		10-20	0.99	0.75	0.422
		20-30	1.31	1.15	0.424
	heading phase	0-10	0.75	0.63	0.543
		10-20	0.72	0.74	0.948
		20-30	0.87	0.85	0.929
	after harvest	0-10	0.88	0.63	0.235
		10-20	0.98	0.60	0.051
		20-30	1.05	0.66	0.010
U-4	stem elongation	0-10	0.76	0.70	0.703
		10-20	1.17	0.98	0.363
		20-30	1.34	1.22	0.639
	heading phase	0-10	0.47	0.47	0.867
		10-20	0.75	0.67	0.743
		20-30	0.95	0.82	0.326
	after harvest	0-10	0.93	0.67	0.143
		10-20	0.98	0.64	0.050
		20-30	1.32	0.74	0.000

Explanations: see Table 1; p – value of the probability of Student's t-test (significance $p < 0.05$)

Table 9. Effect of tillage systems on the yields of cultivated plants

Tillage methods	Winter rapeseed		Winter wheat		Spring barley	
	Mean yields ($t\ ha^{-1}$)	Dunnett's test (p)	Mean yields ($t\ ha^{-1}$)	Dunnett's test (p)	Mean yields ($t\ ha^{-1}$)	Dunnett's test (p)
treatments without soil compaction						
U-1	3.20	x	7.90	x	5.20	x
U-2	3.47	0.133	8.00	0.965	5.30	0.985
U-3	2.19^x	0.011	7.70	0.789	5.00	0.833
U-4	3.53	0.070	6.80^x	0.003^x	4.90	0.603
treatments with soil compaction						
U-1*	3.62	x	8.20	x	4.60	x
U-2	3.59	0.995	7.90	0.440	5.10^x	0.012
U-3	2.85^x	0.011	8.00	0.701	4.70	0.539
U-4	3.60	0.995	7.60^x	0.049^x	4.50	0.929

Explanations: see Table 1

Analysis of the correlations did not show correlation between soil density and the yield of winter rapeseed, winter wheat and spring barley on the lots with and without compacting. Similarly, no significant correlation of the characteristic studied and the yield of test crops under the evaluated cultivation regimes was shown.

DISCUSSION

Among the significant, negative consequences of the application of reduced tillage methods in soil cultivation, the authors indicate, among other things,an increase of soil density and an increase of its compactness as the measurable outcome of it. This is confirmed by the works by Boydas and Turgut (2007), Małecka *et al*. (2012), Raczkowski *et al*. (2012) and Włodek *et al*. (2007).

In our studies, the different regimes of soil cultivation influenced soil compaction depending on the development phase of the studied crops, analysed times and soil layers. During the phase of winter rapeseed full germination, at the depth of 0-10 and 10-20 cm (lots cultivated without compaction) the U-2 cultivation regime decreased the soil resistance significantly. On the compacted lots, the largest increase in soil compaction was recorded following U-3 cultivation (skimming 10 cm + harrowing 10 cm). During the full flowering phase, in the lots without compaction, the conventional plough cultivation regime (the control lot) increased soil compaction in the studied soil layers significantly, compared to the reduced tillage regimes. On the other hand, at the depth of 20-30 cm (lots with compaction), significantly higher soil compaction was recorded regardless of the reduced tillage system applied. Following rapeseed harvest, down to 10 cm (lots without compaction), and following the U-2 cultivation regime (subsoiler, disc harrow, cultivator treatment, harrowing + sowing tillage 20 cm),a significant (almost 2-fold) increase in the value of the analysed characteristic was recorded compared to the plough cultivation regime.

During the winter wheat stem elongation phase, at the depth of 20-30 cm (lots with and without compaction), a significant increase in soil resistance was recorded after the application of the disc harrow, cultivator treatment and harrowing the field (U-3 regime). Similarly, Blecharczyk *et al*. (2007), at the depth of 20-30 cm, found higher values of the analysed characteristic after the application of the stubble field unit. In our experiment, on the lots without compaction (heading phase), significantly lower soil compaction down to 10 cm depth was found after the U-2 cultivation, and at the level of 20-30 cm (lots with compaction) the soil resistance increased significantly afterthe application of the subsoiler and single ploughing. On the other hand, after the harvest of crops on lots without compaction, a significant increase was recorded in the value of the analysed characteristic after U-2 reduced cultivation at the depth of 0-10 cm, and in the soil layer of 10-20 and 20-30 cm after the application of the subsoiler and single ploughing (U-4 regime). However, at the level of 20-30 cm the differences in soil compactness were not confirmed statistically

The results obtained correspond partly with the results presented by other authors. Małecka *et al*. (2007) documented that reduced tillage caused a soil compaction increase in the 0-10 cm layer compared to the plough cultivation. At the level of 20-30 cm, the analysed parameter was significantly higher in the lots with conventional soil cultivation than under reduced tillage. In another study, Małecka *et al*. (2012) recorded lower soil resistance in the 0-10 cm layer after conventional cultivation than after the surface cultivation using the stubble field unit. On the other hand, in the 20-30 cm layer the situation was the opposite. Blecharczyk *et al*. (2007), in turn, after application of disc harrow showed significantly higher compaction of the soil in layersof 0-10 and 10-20 cm, by 0.86 and 1.09 MPa, respectively, compared to the full tillage cultivation. Parylak (2007) documented a significantly stronger influence of the pre-sowing than the post-harvest cultivation on changes in soil compaction under wheat cultivated after wheat at the depth exceeding 10 cm. Pre-sowing application of the cultivation unit instead of sowing tillage increased compaction in the sequence of soil layers by an average of 21.4, 28.1 and 9.4%, respectively. Increase in soil resistance was recorded in particular after the performance of cultivator treatment following the forecrop harvest. In the 0-30 cm layer, the cited author found significantly higher soil compaction compared to the conventional cultivation on lots where the cultivation unit and after the harvest the cultivator were applied before sowing wheat, or where no cultivation treatments were applied. Similarly, Majchrzak and Skrzypczak (2007) found significantly higher soil compaction in the 10-20 and

20-30 cm layers during maize germination phase on lots after post-harvest cultivation. During the vegetation, the correlation was reversed, which meant that during maize harvest higher soil compaction characterised the soil that was ploughed during the spring.

On the other hand, in the study by Majchrowski *et al*. (2007), shallower sowing tillage after skimming caused soil resistance to increase by ca. 14%. Harrowing the soil had a similar effect, increasing the value of the analysed parameter by ca. 13%, compared to tillage applied at variable depths. The cited authors recorded the highest soil density on lots with skimming and sowing tillage limited to 15 cm depth, and the lowest on the lots without skimming but with sowing tillage to the depth of 20 cm.

Blecharczyk *et al*. (2007), as well as Małecka *et al*. (2012), claim that soil compaction increase depends to a significant extent on its depth and time of influence of the cultivation systems, as well as on the timing of readings during the vegetation period. Starczewski *et al*. (2007) add that the value of that parameter also changed under the influence of the diversified intensity of the traffic of heavy agricultural tools and machines across the field.

The results of studies conducted so far indicate a lack of consistency concerning the cultivation systems' influence on the yields of crops. Budzyński *et al*. (2000), after making tillage shallower, at 10 cm, recorded a yield just 4% lower compared to tillage to the depth of 22 cm. Sauermann and Holz (2000), as well as Sieling and Christien (1999), obtained a lower yield of rapeseed, compared to the plough cultivation, after the application of the cultivator and disc harrow. Jankowski (2002), following tillage to the depth of 10 cm, obtained 10% lower yield of rapeseed compared to the medium tillage. Maillard and Vez (1993), following the application of a cultivator in soil preparation for rapeseed, obtained a 12% higher yield than after ploughing. Jaskulski *et al*. (2014) claim that the most favourable effect on winter rapeseed yield is obtained by substituting classic soil cultivation with grubbing or disc harrow application. Bonari *et al*. (1995), on the other hand, indicate the possibility of substituting the classic cultivation with disc harrow treatment as having no significant influence on the yields of that crop. Romaneckas *et al*. (2011) claim that, in the case of precisely performed rapeseed sowing, yield reduction under the influence of reduced tillage systems in the soil cultivation regime may be small or may not occur at all.

Anken *et al*. (2004) did not prove significant influence of the soil cultivation regimes on winter wheat yields. Małecka *et al*. (2012) found that the limitation of the plough cultivation to single ploughing and making the tillage shallower did not diversify the yields of spring barley significantly (its yields were even slightly better – by 5–10%). On the other hand, barley decreased its yields after the application of the stubble field cultivator and disc harrow. Lepiarczyk *et al*. (2009), as well as Orzech *et al*. (2009), recorded a similar decrease in spring barley yield after substituting tillage cultivation with surface cultivation. Conversely, Wesołowski and Cierpiała (2011) found that single ploughing before wheat sowing resulted in a minor decrease in its yield (by 4.5%) compared to the traditional cultivation, while single ploughing complemented by soil compaction before sowing offered a better yield compared to the classic cultivation. Similarly, Małecka *et al*. (2012) state that single ploughing decreased the yield of winter wheat significantly (by ca. 10%) compared to the conventional plough cultivation.

CONCLUSIONS

1. On non-compacted lots of winter rapeseed during full emergence phase the highest penetration resistance was recorded after U-2 cultivation. Conventional cultivation significantly decreased soil penetration resistance at the depth of 20-30 cm. The opposite situation was foundon compacted lots.

2. Plough cultivation (lots without compaction) increased penetration resistance during rapeseed full blossom stage, and after harvest of the crop significantly higher compaction of soil was noted after U-2 cultivation. During the full blossom phase on lots with compaction, regardless of the cultivation simplification variant, at the depth of 20-30 cm significantly higher penetration resistance of the soil was foundcompared to the plough cultivation.

3. In the case of winter wheat, during the stem elongation phase, significantly higher compaction of the soil was found at the depth of 20-30 cm on both lots (without and with compaction) after the application of U-3 cultivation regime compared to the traditional cultivation.

4. During full vegetation, the soil resistance in the examined layers increased, assuming the highest values in the 20-30 cm layer. In the lots with compaction, the highest penetration resistance of the soil was found after the application of the subsoiler and performance of single ploughing (U-4). After the harvest of the crops, compaction significantly increased the soil compaction at the depth of 10-20 cm, particularly afterthe application of conventional cultivation.

5. In the case of spring barley, during the stem elongation stage, on the lots without compaction after the U-2 cultivation, significantly higher soil resistance was found at the depth of 0-10 cm compared to the conventional cultivation. During the heading phase of the cereal, a similar situation was recorded on both lots (without and with compaction) after the U-3 cultivation regime. The same cultivation regime increased soil penetration resistance the most at the depth of 10-20 and 20-30 cm on the compacted lots.

6. After spring barley harvest, at the depth below 20 cm on lots without compaction, a significantly higher soil compactness was found after U-2 cultivation.

On lots with compaction, at the depth of 20-30 cm, omission of post-harvest cultivation and performance of single ploughing caused a highly significant increase of soil compaction.

7. Experimental factors (degree of soil packing and tillage methods) did not significantly affect the performance of the test plants.

8. On compacted lots, as compared to lots without compaction, significantly higher yields of winter rapeseed were found after U-3 cultivation. On both lots (without and with compaction), winter wheat offered the worst yields on lots with reduced tillage limited to the application of the subsoiler and single ploughing (U-4). On lots with compaction, the application of skimming after harvest of the forecrop and performance of pre-winter tillage to the depth of 25 cm (U-2 cultivation) increased significantly the yields of spring barley compared to the conventional cultivation.

REFERENCES

Anken T., Weisskopf P., Zihlmann U., Forrer H., Jansa J., Perhacova K., 2004. Long-term tillage systems effects under moist cool conditions in Switzerland. Soil Till. Res., 78, 171-183.

Arvidsson J., Håkansson I., 1996. Do effects of soil compaction persist after ploughing? Results from 21 long-term field experiments in Sweden. Soil Till. Res., 39, 175-197.

Biskupski A., Włodek S., Pabin J., 2009. The influence of differentiated tillage on selected indices of canopy architecture and yielding of crops (in Polish). Fragm. Agron., 26(4), 7-13.

Blecharczyk A., Małecka I., Sierpowski J., 2007. Long-term effects of tillage systems on physico-chemical soil properties (in Polish). Fragm. Agron., 24(1), 7-13.

Bonari E., Mazzoncini M., Peruzzi A., 1995. Effect of conventional and minimum tillage on winter oilseed rape (*Brassica napus* L.) in sandy soil. Soil Till. Res., 33, 91-108.

Boydas M.G., Turgut N., 2007. Effect of tillage implements and operating speeds on soil physical properties and wheat emergence. Turk. J. Agric. For., 31, 399-412.

Budzyński W., Jankowski K., Szczebiot M., 2000. Effects of simplifying soil tillage and weed control on yielding and production cost of winter oilseed rape. I. Winterhardiness, weed infestation and field of winter oilseed rape (in Polish). Rośl. Oleiste, 21, 487-502.

Camara K., Payne W., Rasmussen P., 2003. Long-term effect of tillage, nitrogen, and rainfall on winter wheat yields in the Pacific Northwest. Agron. J., 95, 828-835.

Jankowski K., 2002. Effect of the depth of ploughing on the economic efficiency of production of winter rape oilseeds (in Polish). Fragm. Agron., 19(2), 273-284.

Jaskulska I, Jaskulski D., Kotwica K., Piekarczyk M., Wasilewski P., 2014. Yielding of winter rapeseed depending on the forecrops and soil tillage methods (in Polish). Annales UMCS, Lublin, E, LXIX(4), 30-38.

Jaskulski D., Kotwica K., Jaskulska I., Piekarczyk M., Osiński G., Pochylski B., 2012. Components of today′s tillage and crop farming systems – production and environmental effects (in Polish). Fragm. Agron., 29(3), 61-70.

Kuc P., 2014. The influence of maize conservation tillage and mineral fertilization on selected physical properties of soil (in Polish). Fragm. Agron., 31(1), 32-43.

Lepiarczyk A., Stępnik K., 2009. Productivity of spring barley cultivated in cereal crop rotation depending on tillage systems (in Polish). Fragm. Agron., 26(1), 59-66.

Maillard A., Vez A., 1993. Resultats d'un essai de culture sans labourdepuis plus de 20 ans a Changins: I. Rendement des cultures, malaides et ravageurs. Revue Suisse Agric., 25(6), 327-336.

Majchrowski P., Kordas L., Parylak D., 2007. Changes in soil environment under different soil tillage and long-term continuous cropping of winter rye (in Polish). Fragm. Agron., 1(93), 164-173.

Majchrzak L., Skrzypczak G., 2007. Influence of reduced tillage systems for maize and cover crops on soil physical properties (in Polish). Fragm. Agron., 1(93), 174-181.

Małecka I., Blecharczyk A., Dobrzeniecki T., 2007. Changes in soil physical and chemical properties caused by reduced tillage (in Polish). Fragm. Agron., 24(1), 182-189.

Małecka I., Blecharczyk A., Pudełko J., 2004. Possibilities of reduced tillage for spring barley (in Polish). Acta Sci., Polonorum Agricultura, 3(2), 89-96.

Małecka I., Blecharczyk A., Sawińska Z., Piechota T., 2014. The effect of tillage systems on aboveground biomass accumulation of spring barley and macronutrients uptake (in Polish). Fragm. Agron., 31(4), 65-74.

Małecka I., Blecharczyk A., Sawińska Z., Piechota T., Waniorek B., 2012. Cereals field response to tillage methods (in Polish). Fragm. Agron., 29(1), 114-123.

Małecka I., Swędrzyńska D., Blecharczyk A., Dytman-Hagedorn M., 2012. Impact of tillage systems for pea production on physical, chemical and microbiological soil properties (in Polish). Fragm. Agron., 29(4), 106-116.

Marks M., Buczyński G., 2002. Soil degradation caused by mechanisation of field operations as well as the methods and possibilities of its prevention (in Polish). Post. NaukRol., 4, 27-39.

Orzech K., Marks M., Dragańska E., Stępień A., 2009. Yielding of spring barley in relation to weather conditions and different methods of cultivation of average soil (in Polish). Acta Agroph., 14(1), 167-175.

Parylak D., 2007. Soil environmental changes under the influence of simplified tillage continuous cropping of winter wheat (in Polish). Fragm. Agron., 1(93), 213-220.

Raczkowski C.W., Mueller J.P., Busscher W.J., Bell M.C., McGraw M.L., 2012. Soil physical properties of agricultural systems in a large-scale study. Soil Till. Res., 119, 50-59.

Romaneckas K., Sarauskis E., Pilipavicius V., Sakalauskas A., 2011. Impact of short-term ploughless tillage on soil physical properties, Winter oilseed rape seedbed formation and productivity parameters. J. Food Agric. Environ., 9, 295-299.

Sauermann W., Holz W., 2000. ReduzierteBodenbearbeitung und BestellungzuWinterraps. Raps, 18. Jg., (3), 132-137.

Sieling K., Christen O., 1999. Yield, N uptake and N leaching after oilseed rape grown in different crop management systems in Northern Germany. Proc. 10th Intern. Rapeseed Congress, Canberra, <www.regional.org.au>, 10.05.2006.

Starczewski J., Turska E., Wielogórska G., 2007. Soil compaction as factor differentiating its physical properties in potato cultivation (in Polish). Fragm. Agron., 1(93), 241-247.

Wesołowski M., Cierpiała R. 2011., Yield of winter wheat depending on pre-sowing tillage method (in Polish). Fragm. Agron., 28(2), 106-118.

Włodek S., Biskupski A., Pabin J., Kaus A., 2007. Yielding of cereals and physical properties of soil under different tillage systems (in Polish). Fragm. Agron., 24(1), 262-268.

WPŁYW UGNIATANIA I METODY UPRAWY ROLI NA ZWIĘZŁOŚĆ GLEBY I PLONOWANIE ROŚLIN W ZMIANOWANIU

Krzysztof Orzech[1], *Maria Wanic*[1], *Dariusz Załuski*[2], *Arkadiusz Stępień*[1]

[1]Katedra Agroekosystemów, Uniwersytet Warmińsko-Mazurski w Olsztynie
[2]Katedra Hodowli Roślin i Nasiennictwa, Uniwersytet Warmińsko-Mazurski w Olsztynie
Plac Łódzki 3, 10-900 Olsztyn
e-mail: krzysztof.orzech@uwm.edu.pl

S t r e s z c z e n i e. W doświadczeniu polowym, realizowanym w latach 2009-2012, oceniano zmiany zwięzłości gleby i plonowania uprawianych w 3-letnim zmianowaniu rzepaku ozimego, pszenicy ozimej i jęczmienia jarego pod wpływem ugniatania roli i 4 sposobów jej uprawy. W fazie pełni wschodów rzepaku ozimego na głębokości 0-10 i 10-20 cm (poletka bez ugniatania) uprawa U-2 (głębosz 40 cm, talerzówka, kultywator, brona, orka siewna 20 cm) istotnie zmniejszyła opór gleby, w odniesieniu do uprawy płużnej (obiekt kontrolny). W poziomie 20-30 cm po uprawie tradycyjnej stwierdzono istotnie mniejszą zwięzłość gleby w stosunku do pozostałych wariantów uprawowych. Na obiektach ugniatanych wykazano sytuację odwrotną. W fazie pełni kwitnienia na poletkach bez ugniatania w badanych poziomach gleby uprawa płużna, w odniesieniu do wariantów uproszczonych, istotnie zwiększyła zagęszczenie gleby. Z kolei na głębokości 20-30 cm (obiekty z ugniataniem), bez względu na wariant upraszczania uprawy, odnotowano istotne większą zbitości gleby, w stosunku do uprawy płużnej. Po zbiorze rzepaku na głębokości do 10 cm (poletka bez ugniatania), po uprawie U-2, odnotowano prawie 2-krotny wzrost wartości analizowanej cechy w stosunku do uprawy płużnej. W fazie strzelania w źdźbło pszenicy na obiektach bez i z ugniataniem największą zbitość gleby stwierdzono na głębokości 20-30 cm po uprawie U-3. Na poletkach bez ugniatania, w fazie kłoszenia, (poletka bez ugniatania) zastosowanie glebogryzarki (uprawa U-2) istotnie zmniejszyło zwięzłość gleby w poziomie do 10 cm. W warstwie 20-30 cm (obiekty z ugniataniem) opór gleby wzrastał, przyjmując najwyższą wartość po głęboszu i orce razówce. Po zbiorze roślin na obiektach bez ugniatania istotny wzrost zwięzłości gleby w stosunku do uprawy płużnej odnotowano po uprawie U-2 na głębokości do 10 cm, a w warstwie 10-20 cm po zastosowaniu głębosza i orki razówki. Stopień ugniecenia i sposób roli istotnie różnicowały wydajność analizowanego zboża. Po zbiorze jęczmienia jarego, na obiektach bez ugniatania, w stosunku do poletek z ugniataniem (głębokość 10-20 cm) stwierdzono istotnie większy opór gleby po zastosowaniu pełnej uprawy płużnej. Podobne efekty uzyskano w poziomach 0-10 i 10-20 cm po uprawie U-2 (podorywka, kultywator, brona + orka przedzimowa 25 cm) oraz na głębokości 20-30 cm po zastosowaniu kultywatora i po wykonaniu orki przedzimowej na głębokość 25 cm (uprawa U-3). Na poletkach ugniatanych, w odniesieniu do nieugniatanych, odnotowano istotnie wyższą wydajność rzepaku ozimego po uprawie U-3. Uprawa pożniwna z głęboszem i przedsiewna z orką razówką najbardziej obniżyły plon pszenicy ozimej, w odniesieniu do uprawy tradycyjnej, przy czym wydajność ziarna na poletkach z ugniataniem gleby w odniesieniu do obiektów bez ugniatania była istotnie wyższa. Na obiektach z ugniataniem zastosowanie podorywki, kultywatorowania i bronowania pola po zbiorze przedplonu i wykonanie orki przedzimowej na głębokość 25 cm (uprawa U-2) istotnie zwiększyło wydajność jęczmienia jarego w stosunku do uprawy tradycyjnej.

S ł o w a k l u c z o w e: ugniatanie, uprawa roli, plonowanie, pszenica ozima, jęczmień jary, rzepak ozimy, zwięzłość gleby