ISSN 1644-0625
ISSN 2300-8504 (online)
www.agricultura.acta.utp.edu.pl

Acta Sci. Pol. Agricultura, 15(1) 2016, 37-50

THE EFFECT OF LONG-TERM TILLAGE SYSTEMS ON SOME SOIL PROPERTIES AND YIELD OF PEA (*Pisum sativum* L.)

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Abstract. Compared with ploughing tillage, no-tillage systems through their diversified effect on soil, modify its properties, and consequently conditions of plants' growth and development. The aim of the study was evaluation of the long-term effect of various tillage systems on the pea yield and some soil properties. The experimental design included 5 tillage variants: 1 – conventional tillage applied annually: skimming + harrowing, sow ploughing to a depth of 25 cm, cultivator unit (cultivator with a string roller), 2 – reduced tillage applied annually (stubble cultivator), 3 – direct sowing into stubble applied annually, 4 – direct sowing applied alternately with reduced tillage, 5 – direct sowing interrupted after 2 years with an annual reduced tillage. The highest pea yields were obtained after reduced tillage, while application of conventional tillage and direct sowing under this plant resulted in a decrease in the grain yield by 7.5 and 11.0%, respectively. Differences in the grain yields in pea between tillage systems resulted mainly from a different plant density per 1 m^2 before harvest. No-tillage systems did not decrease protein content in pea grains compared with pea cultivation in a ploughing system. No beneficial effect was observed of the applied direct sowing interrupted with reduced tillage on the yield of pea. Long-term application of reduced tillage and direct sowing was favorable for increasing moisture and bulk density of the soil as well as for decreasing capillary water capacity. Moreover, it stimulated activity of soil enzymes to a depth of 10 cm.

Key words: enzymatic activities of soil, pea, physical properties of soil, soil tillage

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INTRODUCTION

Recently, there has been observed a worldwide tendency towards conservation agriculture whose task is to protect production potential of the soil [Holland 2004, Brussaard *et al.* 2007, Lal 2007, Morris *et al.* 2010, Santín-Montanyá *et al.* 2014]. In order to fulfill this task, diversification of crops should be provided as well as minimization of the excessive proportion of cereals in the sowing structure and the use of integrated methods of agricultural production, in which a highly significant role may be played by legumes. The argument supporting cultivation of this plant group is their ability to fix atmospheric nitrogen, which has a significant economic and ecological meaning. They are a very good previous crop for most crop plants. Moreover, legume plants' grains may have a great significance in increasing the level of Poland's self--sufficiency in the field of high-protein components of concentrated feeds [Księżak 2000, Andrzejewska 2002, Andrzejewska *et al.* 2005, Podleśny 2005, Prusiński and Kotecki 2006]. Despite numerous advantages of leguminous plants, popularity of this plant group is still low. This phenomenon may be explained by a low profitability of their cultivation and by yield stability. According to the study of Czerwińska-Kayzer and Florek [2012], the highest proportion in the production costs in pea cultivation constitute agronomic treatments (50%) as well as expenditure on the purchase of the seed material (16%). In this respect, searching for lower costs is purposeful, and thus for improving profitability of legume plants cultivation. One of the possibilities may be abandoning expensive and power-consuming ploughing tillage [Dzienia *et al.* 2006, Orzech *et al.* 2003] in favor of other solutions, based on introducing zero-tillage systems, and even on the total abandoning of mechanical activities in the soil or using the so-called direct sowing.

Benefits from using no-tillage systems are visible, as they not only decrease expenditure on energy and labor by about 35% [Dzienia *et al.* 2006], but they also positively affect the soil environment, as they improve the content of organic carbon and water in the soil, soil structure, they reduce crusting of the topsoil layer, reduce the problem of erosion and improve biological properties of the soil [Kladivko 2001, Holland 2004, Dzienia *et al.* 2006, Mestelan *et al.* 2006, Morris *et al.* 2010, Melero *et al.* 2011, Soane *et al.* 2012].

Results of the hitherto prevailing research on the yield of leguminous plants under various tillage systems are ambiguous, which frequently results from different experiment duration [Borstlap and Entz 1994, Małecka 2006, Carr *et al.* 2009, Faligowska and Szukała 2011, Woźniak 2013, Santín-Montanyá *et al.* 2014, Rühlemann *et al.* 2015]. Scientific studies indicate that the causes of decreasing yield level in zero--tillage systems may be among other things: the course of weather conditions [Carr *et al.* 2009, Soane *et al.* 2012, Santín-Montanyá *et al.* 2014], increase in the bulk density and soil compaction, especially in the first years of research [Husnjak *et al.* 2002, Orzech *et al.* 2003, Holland 2004, Dzienia *et al.* 2006, Mestelan *et al.* 2006, Małecka *et al.* 2007]. This may inhibit and reduce field emergence and development of the plant root system, and consequently cause slower increase in the aboveground biomass of plants and accumulation of components, compared with conventional tillage [Soane *et al.* 2012].

The aim of the study was evaluation of the long-term effect of various tillage systems on some physical properties and enzymatic activity of the soil, yield components and pea yield.

MATERIAL AND METHODS

The research was carried out in the years 2011-2014, based on a static field experiment set up in 1999 at the Agricultural Experimental Station Brody (52°26' N; 16°17' E), property of Poznan University of Life Sciences. It was located on soil classified, in accordance with the obliging classification, into an order of lessive soils, subgroup of typic lessive soils, family of boulder clay, and series of light and heavy loamy sands. According to international WRB classification, the soil was included in *Albic Luvisols*, and according to Soil Taxonomy in Typic Hapludalfs, regarding granulation in *loamy sand underlined by loam* [Marcinek and Komisarek 2011]. The soil of the experimental field was classified as bonitation class IIIb-IVa, of a very good rye complex. One-way experiment was set up with a randomized blocks design in four replications.

Field pea was cultivated in a four-course cereal crop rotation (75% of cereals): pea, winter wheat, spring barley, and winter triticale. The plot area was 55 m^2, and for harvest 30 m^2.

The experimental design included 5 tillage variants:

1 – conventional tillage applied annually: skimming + harrowing, pre-winter ploughing to a depth of 25 cm, cultivator unit (cultivator with a string roller),
2 – reduced tillage applied annually (stubble cultivator in autumn),
3 – direct sowing into stubble field applied annually,
4 – direct sowing applied alternately with reduced tillage,
5 – direct sowing interrupted after 2 years with an annual reduced tillage.

Table 1 presents tillage variants used in the experiment in particular years of research. In reduced tillage and direct sowing, sowing was carried out with a Great Plains seeder for direct sowing with disc coulters, whereas in ploughing tillage with a conventional seeder. In autumn, mineral fertilization was applied at the following rate per 1 ha: P – 35 kg and K – 66 kg, while in spring 40 kg $N \cdot ha^{-1}$ were used. Pea cv. Tarchalska was sown at a density of 100 $seeds \cdot m^{-2}$ (280 $kg \cdot ha^{-1}$) in late March, except in 2013, in which sowing was carried out on 16th April. Weeds were controlled with the following preparations: Afalon Dyspersyjny 450 SC at a rate of 1 $dm^{-3} \cdot ha^{-1}$, which was applied directly after sowing pea and Basagran 480 SL at a rate of 2 $dm^{-3} \cdot ha^{-1}$ after pea emergence. Additionally, in reduced tillage and direct sowing, preparation Roundup 360 SL was used at a rate of 4 $dm^{-3} \cdot ha^{-1}$ after harvesting the previous crop, and in spring at a rate of 1.5 $dm^{-3} \cdot ha^{-1}$ along with an adjuvant AS 500 SL at a rate of 1.5 $dm^{-3} \cdot ha^{-1}$.

Table 1. Tillage systems in 2011-2014
Tabela 1. Systemy uprawy roli w latach 2011-2014

Tillage system System uprawy	Year – Rok			
	2011	2012	2013	2014
1	CT – TR	CT* – TR	CT* – TR	CT* – TR
2	RT – UPR	RT – UPR	RT – UPR	RT – UPR
3	NT – SB	NT – SB	NT – SB	NT – SB
4	RT – UPR	NT – SB	RT – UPR	NT – SB
5	RT – UPR	NT – SB	NT – SB	RT – UPR

* CT – TR – conventional tillage – uprawa tradycyjna
RT – UPR – reduced tillage – uprawa uproszczona
NT – SB – direct sowing – siew bezpośredni

At the time of flowering and pod formation, a treatment against pests was used with a preparation Sumi-Alpha 050 EC at a rate of 0.2 $dm^{-3}\cdot ha^{-1}$. Moreover, 2 weeks before harvest, pea plantation was desiccated with a preparation Basta 150 SL at a rate of 3.0 $dm^{-3}\cdot ha^{-1}$.

Harvest was carried out at the turn of July and August once with a Wintersteiger plot combine with an automatic weighing system. Moreover, the following yield components were evaluated: number of plants before harvest in four randomly selected rows on a segment of 1 running meter of each plot, 1000 grain weight, number of pods per plant based on the randomly selected 25 plants from each plot, and grain number per pod based on 50 randomly selected pods. Protein yield was calculated based on the yield and percentage content of protein in grains (nitrogen content × 6.25). Nitrogen in grains was determined with Kjeldahl's method on an automatic analyzer, Kjeltec 2200.

Measurements of physical and biological properties of soil were carried out annually at the stage of florescence in pea. In order to determine physical properties of soil, samples were collected from the layers of 0-5, 5-10 and 10-20 cm in an undisturbed arrangement with cylinders of a volume of 100 cm^3, in which after weighing, drying at a temperature of 105°C and another weighing, moisture and bulk density were determined. Next, cylinders were left to soak in water for 48 hours, in order to determine capillary water capacity.

Soil enzymatic activity in the layer of 0-10 and 10-20 cm was determined at the laboratory of the Department of General and Environmental Microbiology of Poznan University of Life Sciences, based on the determination of the activity of dehydrogenase (DHA), acid phosphatase (PHOS-H) and alkaline phosphatase (PHOS-OH). The activity of DHA was identified by colorimetric method, using as substrate 1% TTC (triphenyl tetrazollium chloride), after 24-hour incubation in 30°C, at wave length 485 nm. Enzyme activity was expressed as μmol $TPF\cdot kg^{-1}\cdot 24h^{-1}$ d.m of soil [Thalmann 1968]. Activity of PHOS-H and PHOS-OH was determined with Tabatabai and Bremner's method [1969] with the use of pNPP (p-Nitrophenylphosphate) as a substrate, after 1-hour incubation at a temperature of 37°C, at a wave length of 400 nm and was expressed as μmol $PNP\cdot g^{-1}\cdot h^{-1}$ d.m of soil.

The obtained results were subjected to statistical evaluation using analysis of variance for orthogonal factorial experiments with the use of STATPAKU program. Significance of differences in the results was evaluated with Fisher-Snedecor's test, while significance of differences between the means was evaluated with Tukey's test ($P = 0.05$).

Weather conditions in the period of research were diversified (Table 2). In the growing season of 2011, spring was warm but dry. Rainfall from March to June oscillated below long-term means, and April and May were particularly dry. In these months, the rainfall constituted 36.6 and 45.1% of the long-term mean respectively, which as a consequence was the cause of inhibiting and reducing emergence of pea, and of slower rate of plant development. In 2012, spring vegetation continued under favorable thermal conditions, especially rainfall conditions. In May, rainfall was by 34%, and in June and July by over 2.5-times higher than in the long-term period. This year may be considered as favorable both for pea emergence and its development, and consequently for a high yield level. The third year of research was characterized by an unfavorable course of thermal conditions in March, as the mean temperature was below zero (-2.5°C). Winter conditions in that month contributed to a significant delay in the sowing time of pea, which caused shortening of the growing season in pea. Further pea development continued under favorable thermal and moisture conditions. Rainfall in May, June and July oscillated above the mean from the long-term period, and June was a particularly humid month. The last year of research had the most favorable weather conditions for growth, development and yield of pea. Temperature and rainfall were above or on a similar level when compared with the means from the long-term period.

Table 2. Mean daily air temperatures and rainfall totals in the growing season in spring in the years 2011-2014
Tabela 2. Średnie dobowe temperatury powietrza i sumy opadów w okresie wegetacji wiosennej 2011-2014

Year – Rok	Growing season – Okres wegetacji					Mean/total Średnia/ Suma
	March marzec	April kwiecień	May maj	June czerwiec	July lipiec	
Mean temperature – Średnia temperatura, °C						
2011	3.1	11.7	14.1	18.6	17.9	13.1
2012	5.7	8.8	14.8	16.0	19.2	12.9
2013	-2.5	8.0	14.4	17.3	20.1	11.5
2014	6.6	10.5	13.1	16.1	21.5	13.6
1961-2010	2.9	7.9	13.2	16.6	18.2	11.8
Rainfall total – Suma opadów, mm						
2011	25.0	13.9	34.0	52.6	175.4	300.9
2012	20.0	22.9	77.2	163.0	197.6	480.7
2013	12.0	15.4	69.8	125.3	67.3	289.8
2014	47.8	46.3	73.5	42.0	83.1	292.7
1961-2010	40.4	38.0	57.4	61.8	77.5	275.1

RESULTS AND DISCUSSION

The grain yields in pea were on a diversified level in particular research years, within the range from 2.13 to 6.45 $Mg \cdot ha^{-1}$ (Table 3). The highest grain yield was observed in the last year of research, with the most favorable distribution of moisture conditions, as in the growing season of pea they were on a higher level than in the long--term period, except in June, in which they were slightly lower. The least favorable distribution of rainfall was observed in 2011 in March, April and May, which is the period of intensive growth and development in pea, which consequently resulted in the lowest grain yield. The harvested grain yield in 2013 was lower than in 2012 and 2014, and probably resulted mainly from a delay in the sowing time and a shorter vegetation as a result of a temperature below zero (-2,5^{o}C) in March. It is widely known that yield level of leguminous plants to a large extent depends on the course of weather conditions, and mainly on the total and distribution of rainfall, which determine field emergence and rate of pea development, and consequently the yield level [Podleśny 2005, Prusiński and Kotecki 2006, Carr *et al.* 2009, Velykis and Satkus 2012, Woźniak 2013, Santín-Montanyá *et al.* 2014].

Table 3. Grain yield of pea in 2011-2014, $Mg \cdot ha^{-1}$
Tabela 3. Plon nasion grochu w latach 2011-2014, $Mg \cdot ha^{-1}$

Tillage system System uprawy roli	Year – Rok				Mean – Średnia 2011-2014
	2011	2012	2013	2014	
CT – TR	2.15	5.33	4.26	5.84	4.40
RT – UPR	2.27	5.14	4.38	7.13	4.73
NT – SB	1.99	4.65	3.77	6.62	4.26
NT/RT – SB/UPR	2.08	4.66	4.27	5.65	4.17
NT 2×/RT 1× SB 2x×/UPR 1×	2.16	4.51	3.38	7.02	4.27
Mean – Średnia	2.13	4.85	4.01	6.45	–
$LSD_{0.05}$ – $NIR_{0,05}$	0.12	0.21	0.40	0.39	0.13

for explanations see Table 1 – objaśnienia pod tabelą 1

The applied tillage systems affected pea yield in various ways in particular years of research. In 2012 and 2013 the yield after conventional and reduced tillage applied permanently was on a similar level, while in 2011, especially in 2014, it was significantly higher after reduced tillage than after ploughing tillage. Applying direct sowing every year in pea cultivation caused significant decrease in the grain yield in all years of research compared with the yield obtained after reduced tillage and after ploughing tillage, except in 2014 in which the grain yield was by 13% higher than after conventional tillage. On average for the study years, the significantly highest grain yield was observed after applying reduced tillage, which was higher by 7.5% than after conventional tillage. On the other hand, the use of direct sowing resulted in a decrease in the grain yield in pea compared with conventional and reduced tillage by 3.2 and 9.9%, respectively. After applying direct sowing interrupted with reduced tillage after a year or two, the grain yield in pea depended on the tillage variant applied in a particular year. The grain yield in pea after applying reduced tillage or direct sowing was similar to the yield obtained in these tillage variants applied permanently. On average for the years of research, the grain yield in pea was on a similar level as after direct sowing applied annually. In literature, there are no explicit results concerning pea yield under various tillage systems. Similar results as in our research were observed by Rühlemann *et al.* [2015], while the studies of Woźniak [2013] indicate a negative effect of zero-tillage on the grain yield of pea compared with conventional tillage. After reduced tillage the grain yield of pea was lower by 21%, while after direct sowing by up to 41%. In the studies of Carr *et al.* [2009] as well as Faligowska and Szukała [2011] a higher grain yield in pea was observed after direct sowing compared with the yield after conventional and reduced tillage, where it was on a similar level. On the other hand, Santín-Montanyá *et al.* [2014] did not observe any significant effect of various tillage systems on the yield and yield components in pea. Such different research results may result from the duration of the experiment, as only after many years of using no--tillage systems, permanent positive changes in soil properties should be expected, and consequently higher yields [Holland 2004, Morris *et al.* 2010]. This is also confirmed by our research, in which after 12 years of using direct sowing, decrease in the grain yield in pea compared with the yield obtained after conventional tillage was insignificant. According to many authors, a higher level of plant yield after direct sowing is observed especially in extremely dry years and regions, which results from a higher water retention and possibility of its greater accumulation in the uncultivated soil [Borstlap and Entz 1994, Carr *et al.* 2009, Morris *et al.* 2010].

Plant density before harvest oscillated on average from 64.1 to 85.2 plants·m^{-2} and was lower from the assumed one, from 17.4% in 2012 to 35.9% in 2013. Statistical analysis confirmed a significant effect of the applied tillage systems on pea density before harvest (Table 4). On average for the years of research, the highest density of pea plants before harvest was observed after reduced tillage, however, no statistical difference was confirmed compared with the density obtained after conventional tillage. Permanent use of direct sowing or interrupting it with reduced tillage resulted in a significant decrease in pea density compared with the one obtained after reduced tillage within the range from 9.4 to 15.9%. However, it should be highlighted that the effect of tillage systems on pea plant density before harvest was slightly different in particular years of research.

Table 4. Pea plant density before harvest in 2011-2014, plants·m^{-2}
Tabela 4. Obsada roślin grochu przed zbiorem w latach 2011-2014, szt.·m^{-2}

Tillage system System uprawy roli	Year – Rok				Mean – Średnia 2011-2014
	2011	2012	2013	2014	
CT – TR	73.6	91.6	75.3	74.8	78.8
RT – UPR	74.6	91.4	70.3	86.2	80.6
NT – SB	62.2	77.8	53.5	77.6	67.8
NT/RT – SB/UPR	72.4	83.6	67.8	60.2	71.0
NT 2×/RT 1× SB 2×/UPR 1×	74.2	81.8	53.8	82.3	73.0
Mean – Średnia	71.4	85.2	64.1	76.2	–
$LSD_{0.05}$ – $NIR_{0,05}$	3.7	7.8	3.4	3.9	2.3

for explanations see Table 1 – objaśnienia pod tabelą 1

Pod number per pea plant was diversified in particular years of research and oscillated on average from 3.2 in 2011 to 7.0 in the last year of research (Table 5). Tillage systems did not significantly affect the discussed trait except in 2014, in which a significantly higher number of pods per plant was observed after using direct sowing compared with the pod number found after reduced tillage. Grain number per pod was slightly diversified by tillage systems (Table 6). On average for the years of research, a slight, though significant, increase in the grain number per pod was observed after no--tillage systems compared with ploughing tillage. Research years had a greater effect on the grain number per pod. In 2011 with the least favorable rainfall distribution this number was 3.5, while in the years with favorable weather conditions it was 4.9-5.2. Tillage systems slightly differently affected the plumpness of pea grains than plant density before harvest (Table 7). The highest 1000 grain weight was observed after permanent application of direct sowing, after which the lowest plant density was observed before harvest. Also in the years of research, in which grain number per pod was lower, a higher 1000 grain weight was observed. Hence, decrease in one yield component may be partially compensated by an increase in another one. In the view of many authors, differences in the grain yield of pea between tillage systems result mainly from plant density before harvest, while other yield components to a lesser degree determine yield height [Carr *et al.* 2009, Velykis and Satkus 2012, Woźniak 2013].

Table 5. Pods number per 1 pea plant in 2011-2014
Tabela 5. Liczba strąków na 1 roślinie grochu w latach 2011-2014

Tillage system System uprawy roli	Year – Rok				Mean – Średnia 2011-2014
	2011	2012	2013	2014	
CT – TR	3.3	5.1	5.4	6.8	5.1
RT – UPR	3.3	5.5	5.5	6.4	5.2
NT – SB	3.1	5.4	5.6	7.0	5.3
NT/RT – SB/UPR	3.2	5.5	5.4	7.4	5.4
NT 2×/RT 1× SB 2×/UPR 1×	3.2	5.4	5.5	7.2	5.3
Mean – Średnia	3.2	5.4	5.4	7.0	–
$LSD_{0.05}$ – $NIR_{0,05}$	ns – ni	ns – ni	ns – ni	0.5	ns – ni

for explanations see Table 1 – objaśnienia pod tabelą 1
ns – ni – non-significant differences – różnice nieistotne

Table 6. Grain number per 1 pea pod in 2011-2014
Tabela 6. Liczba nasion w strąku grochu w latach 2011-2014

Tillage system System uprawy roli	Year – Rok				Mean – Średnia 2011-2014
	2011	2012	2013	2014	
CT – TR	3.3	4.0	5.0	4.7	4.2
RT – UPR	3.4	3.7	5.4	5.1	4.4
NT – SB	3.8	4.0	5.4	4.8	4.5
NT/RT – SB/UPR	3.5	3.6	5.4	5.0	4.4
NT 2×/RT 1× SB 2×/UPR 1×	3.4	3.7	5.3	4.7	4.3
Mean – Średnia	3.5	3.8	5.2	4.9	–
$LSD_{0.05}$ – $NIR_{0,05}$	0.1	ns – ni	ns – ni	0.2	0.1

for explanations see Table 1 – objaśnienia pod tabelą 1
ns – ni – non-significant differences – różnice nieistotne

Table 7. 1000 grain weight in pea in 2011-2014
Tabela 7. Masa 1000 nasion grochu w latach 2011-2014

Tillage system System uprawy roli	Year – Rok				Mean – Średnia 2011-2014
	2011	2012	2013	2014	
CT – TR	267	286	211	247	253
RT – UPR	275	281	213	255	256
NT – SB	278	283	237	254	263
NT/RT – SB/UPR	263	280	219	252	253
NT 2×/RT 1× SB 2×/UPR 1×	266	279	217	252	253
Mean – Średnia	270	282	219	252	–
$LSD_{0.05}$ – $NIR_{0,05}$	5.1	3.3	6.2	3.8	2.1

for explanations see Table 1 – objaśnienia pod tabelą 1

The course of weather conditions as well as various tillage systems had no significant effect on the protein content in pea grains (Table 8). On average for the years of research, protein content in the dry weight of pea grains, depending on the tillage system, oscillated from 209 to 215 $g \cdot kg^{-1}$. Similar results were observed in the study of

Carr *et al.* [2009] as well as Woźniak *et al.* [2014]. Hence, protein yield as a product of its percentage content and grain yield, was diversified by weather conditions and research factor in a similar way as the grain yield (Table 9). Significantly the highest protein yield in pea grains was obtained after reduced tillage applied annually, which for the years 2011-2014 was on average 844 kg·ha^{-1}. Conventional tillage caused decrease in the protein yield, on average by 5.6%, while permanent application of direct sowing of pea by 10.2%. Also, no favorable effect of direct sowing interrupted with surface cultivation was observed on the protein yield. Similarly to the grain yield, the lowest protein yield (385 kg·ha^{-1}) was observed in the first year of research, and the highest in 2014 with the most favorable weather conditions (1184 kg·ha^{-1}).

Table 8. Protein content in pea grains in 2011-2014, g·kg^{-1} d.m.
Tabela 8. Zawartość białka w nasionach grochu w latach 2011-2014, g·kg^{-1}s.m.

Tillage system System uprawy roli	Year – Rok				Mean – Średnia 2011-2014
	2011	2012	2013	2014	
CT – TR	214	199	219	222	214
RT – UPR	210	200	218	212	210
NT – SB	209	201	211	214	209
NT/RT – SB/UPR	214	203	219	223	215
NT 2×/RT 1× SB 2×/UPR 1×	214	200	218	211	211
Mean – Średnia	212	201	217	216	–
$LSD_{0.05}$ – $NIR_{0,05}$	214	199	219	222	214

for explanations see Table 1 – objaśnienia pod tabelą 1

Table 9. Protein yield in pea grains in 2011-2014, kg·ha^{-1}
Tabela 9. Plon białka w nasionach grochu w latach 2011-2014, kg·ha^{-1}

Tillage system System uprawy roli	Year – Rok				Mean – Średnia 2011-2014
	2011	2012	2013	2014	
CT – TR	391	903	793	1 102	797
RT – UPR	406	875	811	1 285	844
NT – SB	354	796	677	1 205	758
NT/RT – SB/UPR	379	806	795	1 071	763
NT 2×/RT 1× SB 2×/UPR 1×	394	768	626	1 259	762
Mean – Średnia	385	829	741	1184	–
$LSD_{0.05}$ – $NIR_{0,05}$	21.3	35.7	74.3	52.1	23.0

for explanations see Table 1 – objaśnienia pod tabelą 1

Tillage systems, through various effects on the soil, modify its physical properties (Table 10). Because of a similar effect of tillage systems on the determined physical properties, they have been presented on average for the years. After no-tillage system, especially after direct sowing, increase in soil moisture was observed in the layer of 0-5, 5-10 and 10-20 cm compared with moisture found after ploughing tillage. Increase in the soil moisture in the layer from 0 to 20 cm is important for plant development, especially in the years with rainfall deficiency. Moreover, higher soil moisture in no-tillage systems increases rate of denitrification, which increases availability of macroelements for crop plants [Doran *et al.* 1998, Soane *et al.* 2012]. Abandoning ploughing in the discussed experiment caused a significant increase in the bulk density of soil, and at the same time decrease in the capillary water capacity in the layers of 0-5 and 5-10 cm, which was also observed in the studies of other authors [Husnjak *et al.* 2002, Orzech *et al.* 2003, Holland 2004, Dzienia *et al.* 2006, Mestelan *et al.* 2006, Rahman *et al.* 2008, Małecka i in. 2007, Morris *et al.* 2010]. Increase in soil density in its top layer may sometimes inhibit plant emergence and reduce their growth and development in the initial growing season [D'Haene 2008, Morris 2010, Soane *et al.* 2012]. However, in the layer of 10-20 cm inverse relationships were observed, as a significantly higher bulk density and lower capillary water capacity was observed in the soil after conventional tillage than after no-tillage system, in which no plough sole was observed. Moreover, long-term experiments indicate that after many years of applying no-tillage systems there occurs a significant improvement in physical properties of the soil caused by the activity of soil fauna, whose result is formation of biogenic pores, mostly with a vertical direction, which enable growth and penetration of the root system [Holland 2004, Morris *et al.* 2010].

Table 10. Soil physical properties in the growing season of pea (mean from 2012-2014)
Tabela 10. Właściwości fizyczne gleby w okresie wegetacji grochu (średnia z lat 2012-2014)

Tillage system System uprawy roli	Water content in soil Wilgotność gleby % v/v			Bulk density Gęstość objętościowa $g \cdot cm^{-3}$			Capillary water capacity Kapilarna pojemność wodna %		
	0-5 cm	5-10 cm	10-20 cm	0-5 cm	5-10 cm	10-20 cm	0-5 cm	5-10 cm	10-20 cm
CT – TR	15.7	17.2	19.0	1.41	1.55	1.75	34.8	31.7	27.4
RT – UPR	17.9	18.9	20.3	1.48	1.63	1.69	31.8	30.3	30.4
NT – SB	19.4	20.5	21.3	1.56	1.69	1.67	29.6	27.9	31.4
$LSD_{0.05}$ $NIR_{0,05}$	1.2	1.0	1.3	0.07	0.08	0.06	2.2	2.1	2.7

for explanations see Table 1 – objaśnienia pod tabelą 1

In the conducted research a higher enzymatic activity was found in the surface soil layer (0-10 cm) after reduced tillage and after direct sowing, compared with soil with ploughing tillage: compared with acid phosphatase 60 and 80%, alkaline phosphatase 22 and 33% as well as dehydrogenase 52 and 66%, respectively (Table 11). In the deeper soil layer (10-20 cm) enzymatic activity was lower than in the surface layer, with a tendency towards higher activity in the soil after ploughing tillage compared with soil after reduced tillage and direct sowing. Similar relationships were also found in earlier research carried out in this experiment [Swędrzyńska *et al.* 2013] as well as in the studies of other authors [Doran *et al.* 1998, Madejón *et al.* 2007, Melero *et al.* 2011, Bielińska and Mocek-Płóciniak 2012]. Reduction in soil loosening through reducing or eliminating cultivation treatments, especially ploughing, decreases rate of mineralization of organic substance. This leads to an increase in the content of organic C in the soil, and to positive changes in soil quality, contributing among other things to an increase in the number of soil microorganisms and in enzymatic activity [Doran *et al.* 1998, Madejón *et al.* 2007, Rahman *et al.* 2008, Swędrzyńska *et al.* 2013]. According to many authors, enzymatic activity is a good indicator of soil fertility, which affects quantity of biochemical mineralization of organic compounds and consequently the supply of nutrients for plants [Doran *et al.* 1998, Madejón *et al.* 2007, Rahman *et al.* 2008, Melero *et al.* 2011, Bielińska and Mocek-Płóciniak 2012].

Table 11. Soil enzymatic activities (mean from 2012-2014)
Tabela 11. Aktywność enzymatyczna gleby (średnia z lat 2012-2014)

Tillage system System uprawy roli	Soil layer Warstwa gleby cm	Acid phosphatase Fosfataza kwaśna μmol PNP·g^{-1}·h^{-1}	Alkaline phosphatase Fosfataza zasadowa μmol PNP·g^{-1}·h^{-1}	Dehydrogenase Dehydrogenaza μmol TPF·kg^{-1}·24h^{-1}
CT – TR	0-10	0.050	0.093	3.75
RT – UPR		0.077	0.110	5.40
NT – SB		0.089	0.121	5.88
$LSD_{0.05}$ – $NIR_{0,05}$		0.012	0.010	0.32
CT – TR	10-20	0.041	0.072	3.60
RT – UPR		0.032	0.054	3.42
NT – SB		0.033	0.055	3.53
$LSD_{0.05}$ – $NIR_{0,05}$		0.008	0.011	ns – ni

for explanations see Table 1 – objaśnienia pod tabelą 1
ns – ni – non-significant differences – różnice nieistotne

ACKNOWLEDGEMENTS

The research has been conducted as part of a long-term program 'Improvement of national sources of plant protein, their production, turnover system and utilization in feeds' registered at no 505.037.07 funded by the Ministry of Agriculture and Rural Development.

CONCLUSIONS

1. The highest grain yield in pea was obtained after reduced tillage. Applying conventional tillage and direct sowing under pea resulted in a decrease in the grain yield by 7.5 and 11.0%, respectively.
2. On average over the study period, differences in the grain yield of pea between tillage systems were connected mainly with plant density before harvest.
3. Various no-tillage systems compared with ploughing tillage did not cause decrease in the protein content in pea grains. Protein yield depended exclusively on the grain yield.
4. No favorable effect of direct sowing interrupted with surface tillage was observed on pea yield.
5. Long-term application of reduced tillage and direct sowing was favorable for increasing soil moisture and bulk density as well as decreasing capillary water capacity. Moreover, it stimulated activity of enzymes in the soil to a depth of 10 cm.

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WIELOLETNIE ODDZIAŁYWANIE SYSTEMÓW UPRAWY ROLI NA WYBRANE WŁAŚCIWOŚCI GLEBY I PLONOWANIE GROCHU (*Pisum sativum* L.)

Abstract. Bezorkowe systemy uprawy roli, poprzez odmienne oddziaływanie na glebę w porównaniu do uprawy płużnej, modyfikują jej właściwości, a w konsekwencji warunki wzrostu i rozwoju roślin. Celem badań była ocena wieloletniego oddziaływania różnych systemów uprawy roli na plonowanie grochu oraz wybrane właściwości gleby. Schemat doświadczenia obejmował 5 wariantów uprawy roli: 1 – uprawa tradycyjna stosowana corocznie: podorywka + bronowanie, orka siewna na głębokość 25 cm, agregat uprawowy (kultywator z wałem strunowym), 2 – uprawa uproszczona stosowana corocznie (kultywator ścierniskowy), 3 – siew bezpośredni w ściernisko stosowany corocznie, 4 – siew bezpośredni stosowany przemiennie z uprawą uproszczoną, 5 – siew bezpośredni przerywany po 2 latach jednoroczną uprawą uproszczoną. Największe plony grochu uzyskano po uproszczonej uprawie roli, natomiast zastosowanie uprawy tradycyjnej oraz siewu bezpośredniego pod tę roślinę skutkowało obniżeniem plonu nasion, odpowiednio o 7,5 i 11,0%. Różnice w plonach nasion grochu pomiędzy systemami uprawy roli wynikały głównie z odmiennej obsady roślin na 1 m^2 przed zbiorem. Sposoby uprawy bezorkowej nie obniżały zawartości białka w nasionach grochu w odniesieniu do jego uprawy w systemie płużnym. Nie odnotowano korzystnego oddziaływania na plonowanie grochu zastosowanego siewu bezpośredniego przerywanego uprawą powierzchniową. Wieloletnie stosowanie uprawy uproszczonej i siewu bezpośredniego sprzyjało zwiększaniu wilgotności i gęstości objętościowej gleby oraz zmniejszaniu kapilarnej pojemności wodnej, a ponadto stymulowało aktywność enzymów w glebie do głębokości 10 cm.

Key words: aktywność enzymatyczna gleby, fizyczne właściwości gleby, groch, uprawa roli

Accepted for print – Zaakceptowano do druku: 16.11.2015

For citation – Do cytowania:

Małecka-Jankowiak, I., Blecharczyk, A., Swędrzyńska, D., Sawinska, Z., Piechota, T. (2016). The effect of long-term tillage systems on some soil properties and yield of pea (*Pisum sativum* L.). Acta Sci. Pol. Agricultura, 15(1), 37-50.