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THE YIELDING OF PEA (*Pisum sativum* L.) UNDER DIFFERENT TILLAGE CONDITIONS

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Abstract. Productivity of plants is determined by multiple factors that directly affect one another, therefore yield variability may be high and difficult to predict. Most often, however, a lower crop yield is achieved in the no-tillage system than in the ploughing system. The reported study evaluated the yielding of pea under conventional (ploughing) tillage (shallow ploughing and harrowing after harvest of the previous crop, ploughing in the autumn), reduced tillage (only cultivator after harvest of the previous crop) and herbicide tillage (only Roundup 360 SL after harvest of the previous crop). The highest pea yield was achieved in the conventional tillage, whereas a lower one – by 40.8% – in the herbicide tillage. The conventional tillage system increased the number of pods per 1 m^2, the number of grains per 1 m^2, and grain weight per plant, compared to the herbicide tillage. The yield of pea was correlated with pod number per 1 m^2, grain number per 1 m^2, grain weight per plant, and plant number per 1 m^2. Correlations were also confirmed between pod number per 1 m^2 and grain number per 1 m^2, as well as between plant number per 1 m^2 and pod number per 1 m^2, and between plant number per 1 m^2 and grain number per plant.

Key words: pea, tillage systems, yield structure

INTRODUCTION

Crop yielding is a resultant of co-effects of cultivar-specific traits, agro-climatic conditions and agrotechnical treatments applied. Out of the agrotechnical factors, the greatest importance is ascribed to fertilization [Kęsik et al. 2011, Nurzyńska-Wierdak et al. 2012], plant protection [Tørresen et al. 1999], crop rotation [Woźniak 1996, López-Bellido et al. 1997], and tillage [Jug et al. 2011, Borowy 2012, Małecka et al. 2012, Woźniak and Haliniarz 2012]. These factors, except for crop rotation, are highly energy-consuming and therefore solutions are sought after that would reduce production expenditures. It pertains especially to unconventional solutions in tillage [Morris et al.

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2010]. In the case of legumes, the fertilization with nitrogen is of little importance as these plants utilize atmospheric nitrogen by means of rhizobia. In contrast, of key significance are tillage and plant protection against agrophages. In the case of tillage, the low-effective and energy-consuming ploughing system is increasingly often substituted for non-inversion tillage [Pikul et al. 1993, Gruber et al. 2012]. Not all solutions are, however, optimal, and opinions on them are either shared or divergent. This has been confirmed in a research by Gruber et al. [2012], where none of the tillage methods was better than the other, whilst each of them was perfect for individual farm conditions. As reported by Morris et al. [2010], the objective of tillage is to provide optimal conditions for plants growth, yet solutions applied sometimes fail to meet expectations. Morris et al. [2010] who referred to investigations by Jones et al. [2006] and Knight [2004], report that crop yield in inversion tillage and non-inversion tillage depends on many factors that affect one another and whose effects are difficult to predict. Nevertheless, the yielding of plants cultivated in no-tillage systems is, generally, slightly lower than of plants from conventional tillage systems. The conservation tillage increases weed infestation [Woźniak 2012], and – consequently – causes yield reduction [Davis et al. 2005, Peigné 2007]. Aura [1999] and Vita et al. [2007] demonstrated than in dry years higher crop yielding was noted in no-tillage system, whereas in years with a higher precipitation the yielding was at a similar level in both systems. Also Hemmat and Eskandari [2004] showed that in dry regions of Iran the highest yields of winter wheat were achieved in sweep plough, whereas these of chickpea – in the no-tillage system. In dry regions, the conventional tillage system with ploughing may be replaced by conservative tillage that increases crop productivity and in a long-term perspective improves soil properties [Hemmat and Eskandari 2004].

The objective of this study was to evaluate the effect of long-term conventional (ploughing) tillage, reduced tillage, and herbicide tillage on the yielding of pea and elements of yield structure.

MATERIAL AND METHODS

The exact field experiment was conducted in the years 2009–2011 at the Experimental Station Uhrusk (51°18'12''N, 23°36'50''E) belonging to the University of Life Sciences in Lublin. The experiment was established on mixed Rendzic Phaeozem with granulometric composition of sandy loam, in the system of randomized sub-blocks, in 3 replications, on plots with the area of 24 m^2. Soil was rich in available forms of phosphorus (2.14 mg P kg^{-1}) and potassium (2.37 mg K kg^{-1}), and had a slightly alkaline pH value (pH_{KCl} = 7.2). The content of inorganic nitrogen (N) in soil accounted for 1.03 g kg^{-1}, whereas that of organic carbon (C) – for 7.60 g kg^{-1}.

The experiment served to evaluate the yielding of pea (Bohun cultivar) cultivated on seeds under conditions of conventional tillage (CT), reduced tillage (RT), and herbicide tillage (HT). The conventional tillage (CT) system included shallow ploughing and harrowing after harvest of the previous crop and ploughing in the autumn. The reduced tillage involved only the use of a cultivator after harvest of the previous crop, whereas the herbicide tillage – the treatment with Roundup 360 SL herbicide (a.s. glyphosate) –

4 l·ha^{-1}. In the springtime, a tillage system including a cultivator, a string roller and a harrow, was applied on all plots.

In each study year, pea (*Pisum sativum* L.) of Bohun cultivar was sown in the first decade of April, in the quantity of 100 seeds per 1 m^2 in row spacing of 20 cm. Before sowing, the following doses of nitrogen, phosphorus and potassium were applied: 20 kg N·ha^{-1}, 17.5 kg P·ha^{-1} and 66.5 kg K·ha^{-1}. Before sowing, the seeds were dressed with a Seed Dressing T (a.s. carbendazim 20% and tiuram 45%). For pea protection against pests, at the early maturation stage of plants and at the pod setting stage, a Karate Zeon 050 CS insecticide (a.s. lambda-cyhalothrin) was applied in a dose of 0.1 l·ha^{-1}, whereas for weed reduction Afalon Dyspersyjny 450 SC (a.s. linuron) in a dose of 1.5 l·ha^{-1} directly after sowing and Fusilade Forte 150 EC (a.s. fluazyfop-P--butyl) in a dose of 1 l·ha^{-1} after emergence of monocotyledonous weeds.

The following biometric traits were determined on each plot: 1) grain yield in t·ha^{-1}, 2) plant number per 1 m^2, 3) pod number per 1 m^2, 4) grain number per 1 m^2, 5) grain weight per plant, and 6) weight of 1000 grains. Pea was harvested with a Wintersteigen plot harvester at seed humidity of 14%. Plant number per 1 m^2, pod number per 1 m^2 and grain number per 1 m^2 were determined twice from the area of 0.5 m^2 of each plot; grain weight per plant was assayed based on 30 plants, whereas 1000 grains weight was determined by counting out 2 × 500 grains.

Table 1. Weather conditions at the Uhrusk Experimental Station

	Years	Months					Total or mean
		March	April	May	June	July	
Precipitation (mm)	2009	106.9	27.0	81.5	169.3	42.7	427.4
	2010	29.5	34.4	150.4	72.6	57.5	344.5
	2011	12.0	34.5	42.0	87.4	147.2	323.1
	1963–2010	29.3	40.8	64.2	72.6	79.8	286.7
Air temperature (°C)	2009	1.0	10.0	13.1	16.4	20.0	17.8
	2010	2.1	8.8	14.8	18.6	21.6	13.2
	2011	2.1	10.2	14.2	18.5	20.1	13.0
	1963–2010	1.2	7.8	13.6	16.7	18.4	11.5

Results achieved were elaborated statistically with the method of analysis of variance (ANOVA), whereas the significance of differences between mean values was evaluated with the Tukey's HSD test (HSD – honestly significant difference), at $P < 0.05$. Correlations between the analyzed parameters were evaluated with the Pearson's correlation coefficients. The course of agro-climatic conditions was presented in Table 1.

RESULTS

The yielding of pea was significantly differentiated by tillage systems (tab. 2). The highest yields of pea were achieved in the conventional tillage system, whereas lower ones (by 40.8%) in the herbicide system. Significant differences in yielding occurred also between conventional and reduced tillage systems (by 21.2%) and between reduced

Tabela 2. Pea grain yield and elements of yield structure

	Tillage systems *(TS)	Years **(Y)			Mean
		2009	2010	2011	
Grain yield ($t \cdot ha^{-1}$)	xCT	3.97	4.44	5.03	4.48
	RT	2.76	3.95	3.89	3.53
	HT	2.08	2.68	3.19	2.65
	mean	2.94	3.69	4.03	-
	y$HSD_{0.05}$ for TS – 0.59; Y – 0.59; TS × Y – NS				
Number of plants per 1 m^2	CT	56.7	56.9	60.6	58.1
	RT	53.2	57.4	58.2	56.2
	HT	47.3	44.0	58.0	49.8
	mean	52.4	52.8	58.9	-
	$HSD_{0.05}$ for TS – NS; Y – NS; TS × Y – NS				
Number of pods per 1 m^2	CT	282	315	364	320
	RT	229	327	345	300
	HT	194	251	285	243
	mean	235	298	331	-
	$HSD_{0.05}$ for TS – 45.9; Y – 45.9; TS × Y – NS				
Number of grains per 1 m^2	CT	1464	1700	2036	1734
	RT	1190	1603	1865	1552
	HT	873	1229	1395	1166
	mean	1176	1511	1765	-
	$HSD_{0.05}$ for TS – 250.4; Y – 250.4; TS × Y – NS				
Grain weight per plant (g)	CT	6.99	7.82	8.31	7.71
	RT	5.15	6.93	7.91	6.66
	HT	4.40	6.06	6.03	5.50
	mean	5.51	6.94	7.42	-
	$HSD_{0.05}$ for TS – 1.78 ; Y – 1.78; TS × Y – NS				
1000 grains weight (g)	CT	245	251	251	249
	RT	240	250	255	248
	HT	230	238	244	238
	mean	239	246	250	-
	$HSD_{0.05}$ for TS – NS; Y – NS; TS × Y – NS				

*TS – tillage systems
**Y – years
xCT – conventional tillage
RT – reduced tillage
HT – herbicide tillage
yHSD – honestly significant difference $P < 0.05$
NS – non-significant difference

and herbicide tillage systems (by 24.9%). Pea yield was also differentiated by study years. The greatest difference was noted between years 2011 and 2009 (by 27.0% on average) and between years 2010 and 2009 (by 20.3%). The evaluation of variance components indicates that grain yield was affected to a greater extent by tillage system (F = 85.90) and to a lesser extent by study year (F = 32.48) (tab. 3). In turn, based on CV values, a lower variability of yielding could be noticed in the conventional tillage (13.4%) than in the reduced (17.3%) and herbicide (18.7%) tillage systems (tab. 4).

Tabela 3. F values of variance components

Traits	*TS	**Y	TS × Y
Grain yield	85.90	32.48	1.57
Plant number (1 m^2)	9.26	6.57	2.04
Pod number (1 m^2)	29.61	44.46	1.69
Grain number (1 m^2)	57.11	59.35	0.81
Grain weight per plant	15.18	12.16	0.75
1000 grains weight	6.76	5.47	0.36

*TS – tillage systems
**Y – years

Tabela 4. Values of coefficients of variation % (CV)

Traits	xCT	RT	HT
Grain yield	13.4	17.3	18.7
Plant number (1 m^2)	9.2	7.0	13.7
Pod number (1 m^2)	13.8	18.6	17.6
Grain number (1 m^2)	16.5	19.4	20.9
Grain weight per plant	13.2	20.5	19.9
1000 grains weight	2.1	4.2	3.8

Explanations as in Table 2

Tillage conditions differentiated plant number per 1 m^2. On plots with herbicide tillage, the number of plants per 1 m^2 was lower than in the conventional and reduced systems, however this difference was not confirmed statistically. The difference in plant number per 1 m^2 occurred also between study years, but it was not confirmed statistically either. The low variability of this trait was also indicated by CV values which in the reduced and conventional tillage systems accounted for 7.0 and 9.2%, respectively, whereas in herbicide system – for 13.7%. Different observations were made in the case of pod number per 1 m^2, because it was found to depend on tillage system. A significantly lower number of pods (by 19.0 and 24.0%) was produced by pea on plots with herbicide tillage than on plots with conventional and reduced tillage systems. Also study years were differentiating pod number per 1 m^2. A lower number of pods (by 21.1 and 29.0%) was set by plants in the year 2009 than in the years 2010 and 2011. Variance components indicate that the number of pods per 1 m^2 depended to a greater extent on study year (F = 44.46) than on tillage system (F = 29.61). Also the number of grains per 1 m^2 was affected by tillage system. The herbicide tillage was observed to decrease grain number per 1 m^2 (by 24.8 and 32.7%), compared to conventional and reduced tillage. This trait was also differentiated by study year. The highest grain number per 1 m^2 was produced by plants in the year 2011, whereas a lower number of grains (by 22.2 and 33.3%) was produced in the other years. Also variance components confirm the effect of tillage system (F = 57.11) and study year (F = 59.35) on values of this trait. In turn, based on coefficients of variation, higher variability of this trait may be stated in the herbicide (20.9%) and reduced (19.4%) systems than in the conventional one (16.5%).

The weight of grains per plant was significantly determined by tillage systems. The herbicide tillage diminished grain weight per plant by 28.6% compared to the conventional tillage. Also under reduced tillage the grain weight was lower than in the conventional system but higher than in the herbicide system, however those differences were not confirmed statistically. In contrast, significant differences occurred between study years, but still higher grain weight (by 25.7%) was produced by plants in 2011 than in 2009. Variance components indicated that grain weight per plant depended to a similar extent on tillage system and study year (tab. 3). Worthy of notice is that the lowest variability of CV of this trait was noted in conventional tillage (13.2%), whereas high variability – in reduced (20.5%) and herbicide systems (19.9%) (tab. 4). The weight of 1000 grains was alike on all plots and was not differentiated by study year. Also CV values showed low variability of this trait (from 2.1 to 4.2%).

Tabela 5. Pearson's correlation coefficients

Traits	Grain field	Plant number (1 m^2)	Pod number (1 m^2)	Grain number (1 m^2)	1000 grains weight
Plant number (1 m^2)	0.78	1.00			
Pod number (1 m^2)	0.94	0.70	1.00		
Grain number (1 m^2)	0.94	0.74	0.99	1.00	
Grain weight per plant	0.88	0.61	0.82	0.82	1.00
1000 grains weight	0.89	0.84	0.74	0.74	-0.14

The Pearson's correlation coefficients achieved in the study enable concluding that crop yielding depended on pod number per 1 m^2, grain number per 1 m^2, grain weight per plant, and plant number per 1 m^2 (tab. 5). Significant correlations occurred also between pod number per 1 m^2 and grain number per 1 m^2, between plant number per 1 m^2 and pod number per 1 m^2 as well as between plant number per 1 m^2 and grain weight per plant.

DISCUSSION

The evaluated tillage systems significantly differentiated the yield of pea grain. In extremely different systems, i.e. in conventional (ploughing) system and herbicide system, this difference accounted for 40.8%. As reported by Knight [2004], in the no-tillage systems the crop yields are, generally, slightly lower than in the conventional systems. Literature data show that higher yields are achieved in the no-till system than in the conventional one, but in dry and semi-desert regions [Guy and Cox 2002, Hemmat and Eskandari 2004]. As claimed by Huang et al. [2008], a higher yield of crops cultivated in the no-tillage system in semi-desert regions may result from a significantly higher capability of soil to accumulate water and from better effectiveness of its management than in the conventional system. In our study, precipitation in the period from pea sowing till harvest (March–July) reached, depending on study year, from 323.1 mm (year 2011) to 427.4 mm (year 2009) with rainfalls preponderance in the period of May-July (tab. 1), which enables recognizing this region as moderately humid. According to López-Bellido et al. [1996], crops productivity in the no-tillage system is decreasing along with an increasing total precipitation, which was also confirmed in the reported experiment. The differences in pea yielding occurred also between study years. The lowest pea yielding was recorded in 2009, which could be due to heavy rainfalls in June of this year, i.e. 169.3 mm (which was 2-fold more than in the other years), and also due to a lower mean air temperature. This resulted in increased weed infestation [Woźniak 2012], and consequently in a reduced pod number per 1 m^2 (by 21.1 and 29.0%), grain number per 1 m^2 (by 22.2 and 33.3%), and grain weight per plant (by 20.6 and 25.7%). It is common knowledge that leguminous plants are characterized by specific traits including, among others, high dependency of pod setting and pod dropping on weather conditions. In addition, their yielding is influenced by co-effects of weather and agrotechnical conditions, therefore the variability of yielding may be high and difficult to predict [Doré et al. 1998]. In the conducted study, the variability was lower in the conventional tillage than in the reduced and herbicide systems. A similar range of variability coefficients (CV) was noted for pod number per 1 m^2, whilst the highest values of CV were determined for grain number per 1 m^2 and grain weight per plant. Also in a research by Doré et al. [1998], the highest variability was noted for grain number per 1 m^2, whereas the lowest one – for grain weight. Based on Pearson's correlation coefficients, it may be stated that the crop yield depended on pod number per 1 m^2, grain number per 1 m^2, grain weight per plant, and plant number per 1 m^2. Correlations occurred also between pod number per 1 m^2 and grain number per 1 m^2, between plant number per 1 m^2 and pod number per 1 m^2 as well as between plant number per 1 m^2 and grain weight per plant. These results confirmed findings of Doré et al. [1998], especially in respect of the correlation between pod number and grain number.

CONCLUSIONS

1. The highest pea yield was achieved in the conventional tillage, whereas the lowest one (by 40.8%) in the herbicide tillage. Significant differences in yielding occurred also

between conventional and reduced tillage systems as well as between reduced and herbicide tillage systems.

2. The conventional tillage system increased the number of pods per 1 m^2, the number of grains per 1 m^2, and grain weight per plant, compared to the herbicide tillage.

3. The yield of pea grain was correlated with the pod number per 1 m^2, grain number per 1 m^2, grain weight per plant, and plant number per 1 m^2. Correlations were also found between pod number per 1 m^2 and grain number per 1 m^2, between plant number per 1 m^2 and pod number per 1 m^2, as well as between plant number per 1 m^2 and grain weight per plant.

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PLONOWANIE GROCHU SIEWNEGO (*Pisum sativum* L.) W RÓŻNYCH WARUNKACH UPRAWY ROLI

Streszczenie. Produkcyjność roślin zależy od wielu czynników bezpośrednio wpływających na siebie, dlatego zmienność plonu może być duża i trudna do przewidzenia. Najczęściej jednak rośliny w uprawach bezpłużnych dają mniejsze plony niż w uprawach płużnych. W prowadzonych badaniach oceniano plonowanie grochu siewnego w warunkach uprawy tradycyjnej (podorywka po zbiorze przedplonu, jesienią orka przedzimowa), uproszczonej (kultywator po zbiorze przedplonu) i herbicydowej (Roundup 360 SL po zbiorze przedplonu). Największe plony grochu siewnego uzyskano w uprawie tradycyjnej, natomiast mniejsze o 40,8% w uprawie herbicydowej. Tradycyjna uprawa roli zwiększała liczbę strąków na 1 m^2, liczbę nasion na 1 m^2 oraz masę nasion z rośliny, w stosunku do uprawy herbicydowej. Plon nasion grochu skorelowany był z liczbą strąków na 1 m^2, liczbą nasion z 1 m^2, masą nasion z rośliny oraz liczbą roślin na 1 m^2. Korelacje wystąpiły również między liczbą strąków na 1 m^2 a liczbą nasion z 1 m^2, a także między liczbą roślin na 1 m^2 a liczbą strąków na 1 m^2 oraz między liczbą roślin na 1 m^2 a masą nasion z rośliny.

Słowa kluczowe: groch siewny, systemy uprawy, struktura plonu

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