Acta Sci. Pol. Hortorum Cultus, 18(1) 2019, 151–160

www.acta.media.pl ISSN 1644-0692 e-ISSN 2545-1405 DOI: 10.24326/asphc.2019.1.15

ORIGINAL PAPER

Accepted: 18.09.2018

TILLAGE MANAGEMENT EFFECTS ON PEA YIELD AND CHEMICAL COMPOSITION OF PEA SEEDS

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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. An exact field experiment was undertaken to determine the yield and chemical composition of pea seeds sown under conditions of: 1) conventional tillage – CT (shallow ploughing and harrowing after the harvest of previous crop, pre-winter ploughing in winter); 2) reduced tillage – RT (stubble cultivator after the harvest of previous crop); and 3) herbicide tillage – HT (only glyphosate after the harvest of previous crop). A cultivation unit was applied on all plots in the springtime. Pea seed yield was higher by 14.1% in the CT than in the RT system and by 50.5% than in the HT system. The CT system was increasing the plant number m^{-2}, number of pods and seeds m^{-2}, seed mass per plant, and 1000 seeds mass, compared to the other systems. Protein content of seeds was at a similar level in all analyzed tillage systems, but was affected by the study year. In turn, the mineral composition of seeds was determined by both tillage system and study year. The seeds harvested from CT plots contained more phosphorus and iron, those from RT plots – more calcium and zinc, whereas those from HT plots – more phytate-P, potassium, magnesium, and copper, compared to the seeds from the other plots.

Key words: legumes, tillage system, seed yield, protein content, mineral composition

INTRODUCTION

Legumes are a valuable group of crops having protein-rich seeds and being commonly applied in human nutrition and animal feeding. Their yields are, however, not always satisfactory and are greatly affected by weather conditions, tillage system and other elements of agricultural engineering [Wang et al. 2010, Małecka-Jankowiak et al. 2016, Simon et al. 2016]. The conventional tillage system is characterized by high energy consumption and strong impact on soil, but these effects may be limited by replacing it with direct sowing or minimal tillage [Rusu 2014]. But still, such solutions are not always optimal and opinions about them are divergent [Simon et al. 2016]. According to Gruber et al. [2012], the choice of tillage system needs to be adjusted to individual habitat and economic conditions of a farm, whereas Morris et al. [2010] reports that it depends on multiple, directly co-acting factors linked with habitat and

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agricultural engineering. It may, generally, be stated that crop yields are lower in the no-tillage than in the tillage system [Gruber et al. 2012, Woźniak 2013]. However, investigations conducted by Carr et al. [2009] prove that in dry years, higher yields of pea are achieved in the no-tillage and reduced tillage systems than in the conventional tillage system, whereas in moderately humid years – yields are similar across tillage systems. Also Hemmat and Eskandari [2004] demonstrated that in arid regions, the crops of pulses were higher in the no-tillage than in the conventional system. In arid regions, the conventional system with ploughing may be replaced by conservation tillage, which increases the plant productivity and improves physical, chemical, and biological properties of soil [Yeboah et al. 2016]. In addition, the system of tillage affects the chemical composition of seeds. Studies conducted by Woźniak et al. [2014] and Małecka-Jankowiak et al. [2016] indicate, however, that it concerns mainly mineral composition and, to a lesser extent, protein content. As demonstrated by Woźniak et al. [2014], seeds originating from the conventional tillage system contained more phosphorus and potassium than those from herbicide tillage, whereas those harvested from the reduced system had more calcium and copper than those from the conventional system.

The goal of this study was to evaluate the effect of conventional, reduced and herbicide tillage on the yield and chemical composition of pea seeds.

MATERIAL AND METHODS

An exact field experiment was conducted in 2014–2016 at the Uhrusk Experimental Station (51°18'12"N, 23°36'50"E) belonging to the University of Life Sciences in Lublin, south-eastern Poland. It was aimed at evaluating the yield and chemical composition of pea (*Pisum sativum* L.) seeds in various tillage systems: 1) conventional (CT), 2) reduced (RT), and 3) herbicide (HT). The experiment was established in randomized blocks design (6 m × 75 m), in 3 replications. The previous crop sown before pea was winter wheat. After its harvest, cut straw was left on the plots (ca. 4.5 t ha^{-1}). In the CT system, shallow ploughing (at the depth of 10–12 cm) and harrowing were performed after winter wheat harvest, as well as pre-winter ploughing in the autumn (25–30 cm). In the RT system, a stubble cultivator was used, whereas in the HT system – the stubble was sprayed with glyphosate. A cultivation unit including a cultivator, a string roller and a harrow, was applied in all plots in the springtime. The soil, the experiment was established on, was Rendzic Phaeozem (IUSS Working Group WRB 2015), containing 24.3% of silty fractions and 13.1% of dusty fraction. It was characterized by P content of 130 mg kg^{-1}, K content of 220 mg kg^{-1}, total N content of 1.05 g kg^{-1}, organic C content of 6.71 g kg^{-1}, and by pH_{KCl} of 7.2. In each study year, pea of Tarchalska variety was sown in the optimal agrotechnical term (since 30 March till 5 April), in the amount of 100 seeds m^{-2}. Before sowing, the plots were fertilized with: 20 kg N ha^{-1}, 17 kg P ha^{-1}, and 66 kg K ha^{-1}.

Following analyses were conducted at each plot: 1) seed yield, 2) plant number m^{-2} at the 32 BBCH stage [Hack et al. 1992], 3) pod number m^{-2}, 4) seed number m^{-2}, 5) seed mass per plant, 6) 1000 seeds mass, and 7) pod length. In addition, seeds were determined for total protein content and mineral composition including: total ash, phosphorus (P), phytate-P, potassium (K), magnesium (Mg), calcium (Ca), iron (Fe), zinc (Zn), and copper (Cu). Pea seeds were collected with a Wintersteiger harvester. The number of plants, pods and seeds were counted at the area size of m^2, whereas seed mass per plant and pod length were determined based on 40 plants. The 1000 seeds mass was established by counting 2 × 500 seeds. Contents of mineral components in seeds were determined after dry mineralization of samples at the temperature of 600°C. The resulting ash was dissolved in 5 mL of 6 M HCI, and the sample was filled up to the volume of 50 mL with distilled water. Determinations were conducted by the acetylene-air flame atomic absorption spectrometry in a Unicam 939 apparatus. Phosphorus phytates were extracted from the sample with 5% TCA for 60 minutes. Afterwards, the extract was centrifuged at 3000 rpm for 10 minutes. Phosphorus phytates present in the supernatant were determined with the spectrophotometric method (λ = 500 nm) using the Wade reagent (0.3 g $FeCl_3$ $6H_2O$ + 3.0 g sulfosalicylic acid per 1 L) [Latta and Skin 1980, Dragičević et al. 2011]. Nitrogen content of pea seeds was determined with the Kjeldahl's method and converted into protein (N × 6.25).

Weather conditions in 2014−2016, during the period since pea sowing till harvest, were presented in Table 1. The highest precipitation was recorded in 2014, especially in May and June, and significantly lesser in 2015 (by 153 mm) and in 2016 (by 74 mm). Also in the multi-year period of 1963−2013, the sum of precipitation in the period since March till July was lower by 35 mm than in 2014. In turn, average air temperatures were insignificantly higher in 2014 than in the other years and in the multi-year period.

Study results were developed statistically by the analysis of variance (ANOVA), whereas the significance of differences between mean values was evaluated with the Tukey's HSD test, $P < 0.05$.

RESULTS

Pea seed yield and its components

Pea seed yield was higher in the CT than in the RT and HT systems by 14.1% and 50.5%, respectively (Tab. 2). Also the plant number m^{-2} was higher in the CT system: by 12.1% and 39.8% than in the RT and HT systems (Tab. 3). Likewise, a higher pod number m^{-2} was determined on CT than on RT and HT plots (by 15% and 49%, respectively). The CT system was also increasing the seed number m^{-2} that was higher by 19.6% and 55.5% compared to the RT and HT systems. Seed mass per plant was also higher in the CT system, i.e. by 19.3% and 34.1% than in

Table 1. Sums of precipitation and average air temperatures at the Uhrusk Experimental Station

Years	Months					Total or mean
	March	April	May	June	July	
Precipitation (mm)						
2014	30	44	152	88	36	350
2015	39	34	62	16	46	197
2016	37	32	70	69	68	276
1963–2013	38	45	72	76	84	315
Air temperature (°C)						
2014	6.1	9.3	13.9	15.8	20.8	13.2
2015	4.7	7.7	13.1	17.1	21.7	12.9
2016	3.5	7.3	13.9	17.0	21.2	12.6
1963–2013	2.0	8.5	14.0	17.1	19.3	12.2

Table 2. Pea seed yield (t ha^{-1})

Year (Y)	Tillage systems (TS)			Mean
	CT[a]	RT	HT	
2014	4.84	3.48	1.89	3.40
2015	5.10	4.70	2.44	4.08
2016	4.96	4.63	3.04	4.21
Mean	4.97	4.27	2.46	–
$HSD_{0.05}$ for TS = 0.20; Y = 0.20; TS × Y = 0.32				

CT[a] – conventional tillage; RT – reduced tillage; HT – herbicide tillage

Table 3. Components of pea seed yield

Year (Y)	Tillage systems (TS)			Mean
	CT[a]	RT	HT	
	Plant number m^{-2}			
2014	74.2	63.3	43,5	60.3
2015	74.6	68.3	40.5	61.1
2016	79.4	69.2	53.4	67.3
Mean	76.1	66.9	45.8	–
$HSD_{0.05}$ for TS = 6.39; Y = 6.39; TS × Y = ns				
	Pod number m^{-2}			
2014	369	272	186	276
2015	416	390	197	334
2016	476	411	259	382
Mean	420	357	214	–
$HSD_{0.05}$ for TS = 53; Y = 53; TS × Y = ns				
	Seed number m^{-2}			
2014	2029	1412	893	1445
2015	2287	2027	945	1753
2016	2620	2136	1241	1999
Mean	2312	1858	1027	–
$HSD_{0.05}$ for TS = 287; Y = 287; TS × Y = ns				
	Seed mass per plant (g)			
2014	6.95	5.03	4.65	5.55
2015	7.75	6.67	5.30	6.57
2016	8.40	6.94	5.27	6.87
Mean	7.70	6.21	5.07	–
$HSD_{0.05}$ for TS = 0.60; Y = 0.60; TS × Y = ns				
	1000 seeds mass (g)			
2014	259	234	223	239
2015	256	226	231	237
2016	251	227	227	235
Mean	255	229	227	–
$HSD_{0.05}$ for TS = 11; Y = ns; TS × Y = ns				
	Pod length (cm)			
2014	6.31	6.12	5.14	5.86
2015	5.80	6.08	4.92	5.60
2016	6.30	6.00	5.13	5.81
Mean	6.14	6.07	5.06	–
$HSD_{0.05}$ for TS = 0.61; Y = ns; TS × Y = ns				

CT[a] – conventional tillage; RT – reduced tillage; HT – herbicide tillage

Table 4. Effect of tillage system (TS) and study year (Y) on the yield and its components

Specification	Value	TS	Y	TS × Y
Yield (t ha^{-1})	*F*	547.17	61.54	13.74
	p	<0.01	<0.01	<0.01
Plant number m^{-2}	*F*	77.74	4.71	1.06
	p	<0.01	0.02	0.40
Pod number m^{-2}	*F*	51.41	13.03	1.18
	p	<0.01	<0.01	0.35
Seed number m^{-2}	*F*	67.14	12.17	1.15
	p	<0.01	<0.01	0.36
Seed mass per plant (g)	*F*	62.37	17.40	1.66
	p	<0.01	<0.01	0.20
1000 seeds mass (g)	*F*	28.23	0.44	0.74
	p	<0.01	0.64	0.57
Pod length (cm)	*F*	12.59	0.65	0.28
	p	<0.01	0.53	0.88

Table 5. Content of total protein in pea seeds (%)

Year (Y)	Tillage systems (TS)			Mean
	CT[a]	RT	HT	
2014	21.8	22.0	20.1	21.3
2015	22.8	21.5	21.0	21.8
2016	23.0	22.0	23.0	22.7
Mean	22.5	21.8	21.4	–
$HSD_{0.05}$ for TS = ns; Y = 0.8; TS × Y = ns				

CT[a] – conventional tillage; RT – reduced tillage; HT – herbicide tillage

Table 6. Content of total ash (%) in pea seeds

Year (Y)	Tillage systems (TS)			Mean
	CT[a]	RT	HT	
2014	3.25	2.73	3.14	3.04
2015	3.49	2.94	3.27	3.24
2016	3.15	2.72	3.12	2.99
Mean	3.30	2.80	3.18	–
$HSD_{0.05}$ for TS = 0.13; Y = 0.13; TS × Y = ns				

CT[a] – conventional tillage; RT – reduced tillage; HT – herbicide tillage

Table 7. Content of macroelements in pea seeds

Year (Y)	Tillage systems (TS)			Mean
	CT[a]	RT	HT	
Phosphorus (g P kg^{-1} d.m.)				
2014	3.72	3.68	3.62	3.67
2015	3.95	3.71	3.58	3.75
2016	4.25	3.73	3.94	3.97
Mean	3.97	3.71	3.71	–
$HSD_{0.05}$ for TS = 0.24; Y = 0.24; TS × Y = ns				
Phytate-P (g kg^{-1} d.m.)				
2014	1.70	1.92	2.18	1.93
2015	1.69	1.93	2.09	1.90
2016	1.82	2.01	2.38	2.07
Mean	1.73	1.95	2.22	–
$HSD_{0.05}$ for TS = 0.13; Y = 0.13; TS × Y = ns				
Potassium (g K kg^{-1}d.m.)				
2014	9.24	8.83	10.12	9.40
2015	9.15	8.53	10.03	9.24
2016	9.51	8.81	9.72	9.35
Mean	9.30	8.73	9.96	–
$HSD_{0.05}$ for TS = 0.46; Y = ns; TS × Y = ns				
Magnesium (g Mg kg^{-1} d.m.)				
2014	0.93	0.95	1.00	0.96
2015	0.96	0.88	1.03	0.96
2016	0.89	0.87	0.98	0.91
Mean	0.93	0.90	1.00	–
$HSD_{0.05}$ for TS = 0.07; Y = ns; TS × Y = ns				
Calcium (g Ca kg^{-1} d.m.)				
2014	0.76	0.85	0.70	0.77
2015	0.72	0.77	0.75	0.75
2016	0.58	0.75	0.58	0.64
Mean	0.69	0.79	0.67	–
$HSD_{0.05}$ for TS = 0.11; Y = 0.11; TS × Y = ns				

CT[a] – conventional tillage; RT – reduced tillage; HT – herbicide tillage

Table 8. Content of microelements in pea seeds

Year (Y)	Tillage systems (TS)			Mean
	CT[a]	RT	HT	
Iron (mg Fe kg^{-1} d.m.)				
2014	88.6	72.1	58.9	73.2
2015	88.6	71.7	58.0	72.7
2016	87.9	69.2	54.4	70.5
Mean	88.4	71.0	57.1	–
$HSD_{0.05}$ for TS = 4.61; Y = ns; TS × Y = ns				
Zinc (mg Zn kg^{-1} d.m.)				
2014	40.8	49.8	42.3	44.3
2015	40.4	48.0	42.0	43.5
2016	42.9	51.6	44.9	46.4
Mean	41.4	49.8	43.0	–
$HSD_{0.05}$ for TS = 5.66; Y = ns; TS × Y = ns				
Copper (mg Cu kg^{-1}d.m.)				
2014	6.12	7.12	7.76	7.00
2015	5.96	6.56	7.72	6.75
2016	6.19	6.20	7.74	6.71
Mean	6.09	6.63	7.74	–
$HSD_{0.05}$ for TS = 0.80; Y = ns; TS × Y = ns				

CT[a] – conventional tillage; RT – reduced tillage; HT – herbicide tillage

Table 9. Effect of tillage system (TS) and study year (Y) on the chemical composition of pea seeds

Specification	Value	TS	Y	TS × Y
Protein (%)	*F*	2.32	9.13	4.31
	p	0.45	0.01	0.68
Ash (%)	*F*	52.61	12.78	0.61
	p	<0.01	<0.01	0.65
Phosphorus (g kg^{-1} d.m.)	*F*	4.36	4.68	1.13
	p	0.03	0.02	0.37
Phytate-P (g kg^{-1} d.m.)	*F*	48.19	6.52	0.87
	p	<0.01	<0.01	0.49
Potassium (g kg^{-1} d.m.)	*F*	23.39	0.42	0.88
	p	<0.01	0.66	0.49
Magnesium (g kg^{-1} d.m.)	*F*	7.58	1.98	0.84
	p	<0.01	0.16	0.51
Calcium (g kg^{-1} d.m.)	*F*	4.35	5.50	0.74
	p	0.02	0.01	0.57
Iron (mg kg^{-1} d.m.)	*F*	150.4	1.26	0.20
	p	<0.01	0.30	0.93
Zinc (mg kg^{-1} d.m.)	*F*	8.12	0.96	0.02
	p	<0.01	0.40	0.99
Copper (mg kg^{-1} d.m.)	*F*	14.44	0.51	0.52
	p	<0.01	0.60	0.71

the RT and HT systems. Similarly, 1000 seeds mass was higher by 10.2–11.0% in CT than in the RT and HT systems. In addition, in CT and RT systems, plants developed longer pods compared to the HT system. Pea seed yield was also determined by study year, i.e. it was higher by 19.2% in 2016 than in 2014. Also 2016 was superior over 2014 regarding the plant number m^{-2}, pod number m^{-2}, seed mass per plant, and seed number m^{-2}

The evaluation of variance analysis components indicated that the seed yield as well as plant, pod and seed numbers m^{-2}, and seed mass per plant were affected to a greater extent by tillage systems than by study year (Tab. 4).

Protein content and chemical composition of pea seeds

Protein content of pea seeds was diversified only by study years (Tab. 5). Its higher value was determined in the seeds from 2016 than in those from the other years. The tillage system had little effect on protein content of seeds.

The CT system was increasing the total ash content of seeds, compared to the RT system (Tab. 6). A higher ash content was also assayed in the seeds from HT than from RT plots. The seeds harvested from CT plots were also characterized by a higher phosphorus content than seeds from RT and HT plots. It needs to be emphasized, however, that it was in major part represented by phytate-P (Tab. 7). In the seeds harvested from CT plots, the content of phytate-P constituted 43.5%, whereas in these from RT and HT plots it constituted 52.5% and 59.8% of total phosphorus, respectively. In turn, potassium and magnesium contents were significantly higher in seeds from the HT system compared to CT and RT systems. In turn, a higher content of calcium was determined in the seeds from the RT than from the HT system. Contents of microelements, i.e. iron, zinc and copper, in pea seeds were influenced only by the system of tillage (Tab. 8). More iron was found in the seeds from CT plots, more zinc in those from RT plots, whereas more copper in seeds from HT plots, compared to the other plots.

Chemical composition of pea seeds was also diversified by study years. A higher ash content was assayed in the seeds harvested in 2015 than in those from 2014 and 2016. In turn, more phosphorus was found in seeds from 2016 than in those from 2014, whereas a higher phytate-P content was determined in seeds from 2016 compared to those harvested in other years of the study. In turn, calcium content was higher in the seeds from 2014 than in those from 2016. In contrast, no significant effect of study years was found regarding the contents of iron, zinc and copper in pea seeds.

The evaluation of variance analysis components indicated that contents of total ash and phytate-P were to a greater extent influenced by the tillage system than by the year of the study (Tab. 9).

DISCUSSION

Results obtained in this study demonstrate that crop yielding varies between conventional tillage and no-tillage systems and is determined by habitat conditions. Many scientific works have indicated that in arid regions, definitely higher yields are obtained by plants in the no-tillage system, whereas in the regions with regular precipitation – in the conventional tillage system [Hemmat and Eskandari 2004, De Vita et al. 2007, Morris et al. 2010]. Also according to Carr et al. [2009], in regions poor in precipitation, the yield of pea may be increased by eliminating the conventional tillage and replacing it by direct sowing or reduced tillage. In the region with regular precipitation analyzed by Woźniak [2013], a higher pea seed yield was obtained in the conventional than in the no-till system. In the present study, a higher pea seed yield was achieved in each study year in the CT system compared to RT and HT systems, but an especially large difference (over 50%) occurred between CT and HT systems. It may be concluded that the CT system offered better conditions for plant growth and development than the RT and HT systems did, which was manifested in a higher plant number m^{-2}, higher numbers of pods and seeds m^{-2}, longer pods, higher seed mass per plant, and higher 1000 seeds mass. In the experiment conducted by Carr et al. [2009], lower yield in the conventional tillage system, compared to no-tillage, was due to a lower plant number m^{-2}, whereas in the study carried out by Woźniak [2013] – also to a lower seed mass per plant. Pea yield is significantly affected by weather conditions in the growing season. In the study by Woźniak [2013], the difference in yield between study years reached 27%, but as reported by Carr et al. [2009], it may be significantly greater. In the present study, the average difference in yields was 19.2%, although it depended on tillage system. According to Doré et al. [1998], pea yield is determined by the co-effects of factors linked with weather conditions and agricultural engineering, hence variability in yields may be high and difficult to predict. In the present study, the greatest variability was observed for seed number m^{-2}.

The system of tillage affects also the chemical composition of seeds, but has a lesser impact on protein content of seeds. It was confirmed in investigations conducted by Woźniak et al. [2014] and Małecka-Jankowiak et al. [2016], which demonstrated protein content in pea seeds to be similar in the conventional tillage and no-tillage systems. In contrast, as reported by Amarakoon et al. [2012], the tillage system determines the mineral composition of pea seeds. Also Woźniak et al. [2014] demonstrated higher contents of ash, phosphorus and potassium in pea seeds harvested from plots cultivated in conventional and reduced tillage systems compared to the herbicide tillage, as well as higher calcium content in seeds from reduced than herbicide tillage system. In the present study, higher contents of phosphorus and iron were assayed in the seeds from CT plots, those of calcium and zinc in the seeds from RT plots, whereas those of potassium, magnesium, copper and phytate-P in the seeds from HT plots. According to Wang et al. [2010], ash content of pea seeds depends on the year, habitat conditions, and variety. In the cited work, ash content ranged from 2.57 to 2.79%, which was similar to results achieved in the present study (from 2.80 to 3.30%). Also Amarakoon et al. [2012] reported that the mineral composition of pea seeds was subject to significant changes as affected by plant genotype and habitat conditions.

Pea seeds are good sources of iron, zinc and magnesium in human nutrition, but they may also contain high quantities of phytates [Loewus 2002]. These compounds exhibit antinutritional properties as they reduced the availability of iron, zinc, phosphorus, and calcium [Tavajjoh et al. 2011]. As shown by Sandberg [2002], they form complexes with iron and zinc, which may lead to deficiencies of these elements in food products. They serve also some positive functions, for they reduce the risk of ischemic heart disease, arterial atherosclerosis and diabetes development as well as display antioxidative properties [Kumar et al. 2010]. They are synthesized during the seed ripening and constitute 60–90% of total phosphorus [Loevus 2002]. In the present study, phytate-P represented from 43.5% of total phosphorus in the CT system to 59.8% in the HT system.

CONCLUSIONS

In summary, it may be concluded that higher pea yield was obtained in the CT than in the RT and HT systems. Pea sown in the CT system was characterized by higher plant number m^{-2}, higher pod and seed number m^{-2}, as well as higher seed mass per plant and 1000 seeds mass compared to the RT and HT systems. Seed yield was also significantly differentiated by study years. Protein content of pea seeds depended only on study year and was higher in 2016 than in the other years. In turn, the mineral composition of seeds was affected by both tillage system and study year. The seeds harvested from CT plots contained more phosphorus and iron, those collected from RT plots – more calcium and zinc, whereas those harvested from HT plots – more phytate-P, potassium, magnesium, and copper compared to the seeds from the other plots.

ACKNOWLEDGEMENTS

Research supported by Poland's Ministry of Science and Higher Education as part of the statutory activities of the Department of Herbology and Plant Cultivation Techniques, University of Life Sciences in Lublin.

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