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ENHANCING OF WINTER WHEAT PRODUCTIVITY BY THE INTRODUCTION OF FIELD PEA INTO CROP ROTATION

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The aim of our study was to find out the influence of different preceding crops and weather in particular years on the production ability of winter wheat in crop rotation with 80% share of cereals. The long-term field trial with 40, 60 and 80% share of cereals and two levels of fertilisation (H_1 mineral fertilisation + organic manure Veget®; H_2 mineral fertilisation only) was carried out in the very warm and dry area of continental climate on Luvi-Haplic Chernozem. In crop rotation with 80% share of cereals, winter wheat was sown after two preceding crops: pea and winter barley. In the years 2013–2015, the weight of 1,000 grains, bulk density, share of grains over 2.8 + 2.5 mm sieve, grain yield and straw yield were investigated. In crop rotation with 80% share of cereals, the significantly higher grain yield of winter wheat was recorded after preceding crop of field pea (6.18 t/ha) by comparison with winter barley as preceding crop (5.19 t/ha). The statistically significantly higher straw yield of winter wheat was observed after field pea (8.38 t/ha) in comparison to winter barley (7.29 t/ha). The weight of 1,000 grains, bulk density, share of grains over 2.8 + 2.5 mm sieve were statistically significantly higher after field pea in comparison to winter barley. The winter wheat grain yield can be increased by the preceding crop pea and the combination of mineral and organic fertilisation in substantial degree.

Key words: share of cereals, legumes, preceding crop, grain yield, bulk density, weight of thousand grains

Economic conditions are forcing farmers to grow crops that yield high revenue, leading to cereal-dominated crop rotations with increasing risk due to unfavourable preceding crops or preceding crop combinations (Sieling & Christen 2015). Crop rotations in Slovakia are constantly adapted to economic conditions and political intentions. In agricultural co-operative farms, the so-called free crop rotation is applied. It means that farms grow one or two main crops. Cropping systems based on winter wheat are particularly widespread in non-irrigated land, wherein other higher yielding spring crops may fail, due to water shortage in summer. In these conditions, the frequency of wheat within rotations becomes very high and continuous cropping may often be the only profitable option. Rotations based on high frequency of wheat are at risk of reduced yield levels (Bonciarelli *et al.* 2016). Indeed, it has been shown that, in the short term, wheat following wheat gives a lower yield than wheat following a different crop (Sieling *et al.* 2005). Legume production has declined in most of Europe, from 4.7% of arable land in 1961 to 1.6% in 2013 (FAOstat 2015). There are many reasons why farmers do not grow legumes, including specialisation in cereal crop production, low and unstable yields (Cernay *et al*. 2015; Reckling *et al.* 2016), low and unpredictable policy support (Bues *et al*. 2013), and inability to recognise or evaluate the long-term benefits of legumes within cropping systems (Preissel *et al.* 2015). Grain legumes are known to increase the soil mineral nitrogen (N) content, reduce the infection pressure of soil borne pathogens and hence enhance subsequent cereals yields (Hauggaard-Nielsen *et al.* 2012). While

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the effect of legumes on yield of the following crop is easily measured, changes in root growth and pressures from pests and pathogens are harder to quantify. Legumes generally have lower gross margins than cereals or oilseeds, but their rotational effects increase the gross margins of subsequent crops, so assessment of legumes needs to be performed at the cropping system scale (Preissel *et al.* 2015). Sarunaite *et al.* (2013) evaluated the possibility to associate cereals with legumes as an alternative double-cropping system for supplying biological N to cereals. Pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.) and lupin (*Lupinus angustifolius* L.) grain legumes are the most adapted species to temperate growing conditions (Hauggaard-Nielsen *et al.* 2012). Field pea belongs among agricultural plants with great agronomical importance. The primary importance of legumes is their ability to fix atmospheric nitrogen (Danilovič & Šoltýsová 2010). Bielek (1998) reported that they fixed about 10 kg/ha/year of nitrogen in condition of Slovakia. The potential of field pea is markedly higher, pea may fix about 48–167 kg/ha N (Nielsen *et al.* 2009). The grain yield of spring wheat can be enhanced following field pea (Carr *et al.* 2008).

The aim of our research was to investigate the influence of preceding crop, fertilisation and weather in particular years on the grain yield and yield components of winter wheat in the crop rotation with 80% share of cereals.

MATERIAL AND METHODS

The research was realised in 2013–2015 in a long-term field trial. The trial was established in 1974 at Experimental Station Borovce, which belongs to Research Institute of Plant Production in Piešťany. In 2013–2015, the variety of winter wheat Bertold was used.

Long-term field trial is situated on Luvi-Haplic Chernozem, pH 5.5–7.2, with a humus content of 1.8–2.0%. The area has continental pattern of climate with long-term average sum of annual rainfall of 593 mm and 358 mm rainfall during vegetation period. Long-term average of annual temperature is

T a b l e 1

Weather conditions in the experimental years 2013–2015 on the stand Borovce

Month	n (1951–1980)		2013		2014		2015	
	x_{td} [C°]	$\sum$ [mm]	x_{td} [C°]	$\sum$ [mm]	x_{td} [C°]	$\sum$ [mm]	x_{td} [C°]	$\sum_z$ [mm]
January	–1.8	32	–2.55	69.8	–0.21	34.4	–1.29	64.5
February	0.2	33	–0.77	90.3	1.22	33.2	–1.51	28.9
March	4.2	32	0.84	75.3	6.14	20.7	2.71	53.1
April	9.4	43	9.15	17.4	9.65	65.7	8.17	21.9
May	14.1	54	13.52	67.4	13.16	110.3	13.27	58.9
June	17.7	80	17.51	70.1	18.0	34.5	18.34	21.0
July	18.9	76	20.71	3.0	19.85	120.1	22.28	24.8
August	18.4	68	20.12	112.9	17.12	50.9	21.94	111.0
September	14.5	38	11.59	75.6	14.06	122.9	14.13	47.6
October	9.6	42	8.71	29.1	9.19	53.3	7.12	63.5
November	4.6	51	3.33	59.7	4.78	24.9	3.45	40.5
December	0.3	46	–0.57	9.9	–0.23	49.4	–0.06	22.0
x_{td} [°C]	9.2	–	8.47	–	9.40	–	9.05	–
$\sum_z$ [mm]	–	595	–	680.4	–	720.3	–	557.7

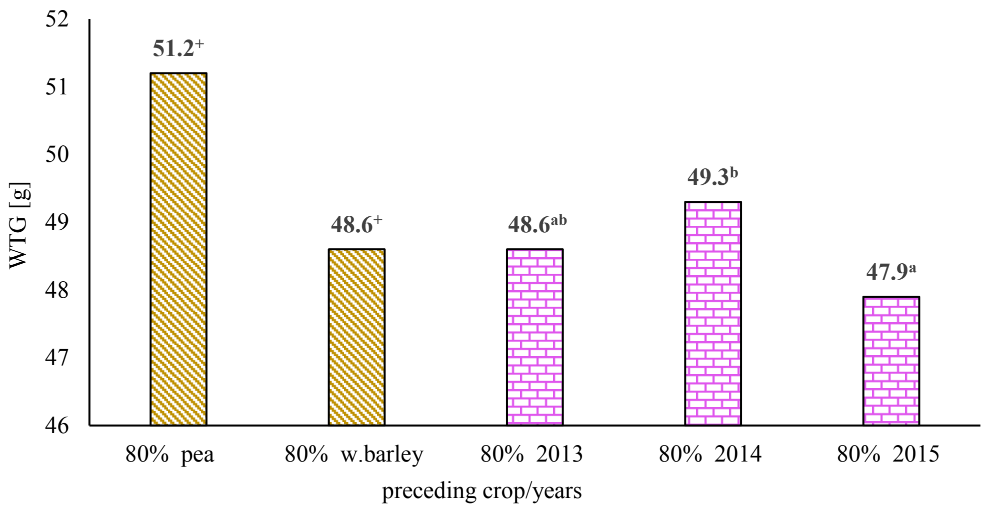
n – long-term (30-year) normal; x_{td} – average air temperature; $\sum$ – sum of precipitation

9.2°C, and in vegetation period, it is 15.5°C (Table 1). In the field experiment, there were crop rotations with 40%, 60% and 80% proportion of cereals. Crops in different crop rotations are presented in Table 2. In crop rotation with 80% share of cereals, winter wheat was grown after two preceding crops: field pea and winter barley. The fertilisation level H_1: fertilisation by phosphorus and potassium was carried out by balance method according Bizík *et al*. (1998). Nitrogen fertilisation was used according to the content of nitrogen in soil (soil samples were taken from 0.0 to 0.3 m of soil profile) + organic manure Veget® in dose of 5 tons per hectare. The composition of organic fertiliser Veget® [ČOV, a. s., (joint stock company Cleaner of Waste Water), Slovenská Ľupča, Slovakia] is as follows: dry matter content at a minimum of 85% (includes combustible matter content 75%; total N content 2.5–3.0%; total P_2O_5

T a b l e 2

The crop rotations with 40%, 60% and 80% share of the cereals

Crop rotations		
40% share of cereal	60% share of cereal	80% share of cereal
1. pea	1. pea	1. winter wheat
2. winter wheat	2. winter wheat	2. spring barley
3. silage maize	3. winter barley	3. pea
4. spring barley	4. silage maize	4. winter wheat
5. grain maize	5. spring barley	5. winter barley



Average weight of one thousand grains after different preceding crop – pea; w. barley – winter barley; +significant difference at the level α = 0.05. Average weight of one thousand grains in years after both preceding crops – different literae – significant difference at the level α = 0.05; equal literae – insignificant difference at the level α = 0.05.

Figure 1. The weight of one thousand grains [g] of winter wheat after field pea and winter barley in years 2013–2015

content 0.5–2.0%, and K_2O content 1.5%), ratio C:N 13:1, and pH (in water) 8.5. Veget® is produced from waste materials after industrial antibiotics production. The fertilisation level H_2: fertilisation of phosphorus, potassium and nitrogen was applied at the same level as H_1 except organic manure Veget®.

The data was computed by multiple-way analysis of variance (ANOVA) and the *LSD* multiple range test was used at the 0.05% level. STATISTICA 6. 1 (StatSoft Inc., Tulsa, USA) software was used.

RESULTS AND DISCUSSION

In 2013–2015, the average monthly temperatures and monthly sums of monthly rainfall (Table 1) differ from the long-term average (1951–1980). In 2013, the average monthly temperature was lower by 3.36°C than in the long-term average. In 2013, the monthly sum of rainfall was higher in February and in March than the long-term average. In 2014, the monthly sum of rainfall in May was higher by 56.3 mm than the long-term average. On the contra-

T a b l e 3

The influence of fertilisation and preceding crop on the weight of one thousand grains of winter wheat (analyse of variance)

Factor	WTG [g]				
	df	MS	F	*P*	$LSD_{0.05}$
Fertilisation (A)	1	3.15	0.89	–	–
PC (B)	1	82.43	23.21	+	1.11
A × B	1	7.44	2.10	–	–
Years (C)	2	32.60	9.18	+	1.64
A × C	2	2.87	0.81	–	–
B × C	2	10.19	2.87	–	–
Total	47	7.10	–	–	–
Error	33	3.55	–	–	–

PC – preceding crop; *df* – degrees of freedom; MS – average squares, F – F-test; *P* – effect of a factor significant at the level 0.05; $LSD_{0.05}$ – least significant difference at the level α = 0.05

T a b l e 4

The influence of fertilisation and preceding crop on weight bulk and share of grains over 2.8 + 2.5 mm sieve of winter wheat (analyse of variance)

Factor	Bulk density [g/l]					Share of grains over sieve 2.8 + 2.5 mm [%]				
	df	MS	F	*P*	$LSD_{0.05}$	*df*	MS	F	*P*	$LSD_{0.05}$
Fertilisation (A) (A [A]	1	70.1	0.26	–	–	1	7.76	0.69	–	–
PC (B)	1	3536.33	13.35	+	9.56	1	181.35	16.04	+	1.98
A × B	1	1.33	0.01	–	–	1	49.01	4.34	+	3.72
Year (C)	2	6460.4	24.39	+	14.13	2	205.00	18.14	+	2.92
A × C	2	492.7	1.86	–	–	2	14.98	1.33	–	–
B × C	2	2807.0	10.60	+	24.63	2	16.75	1.48	–	–
Total	47	710.47	–	–	–	47	25.11	–	–	–
Error	33	264.8	–	–	–	33	11.30	–	–	–

PC – preceding crop; *df* – degrees of freedom; MS – average squares, F – F-test; *P* – effect of a factor significant at the level 0.05; $LSD_{0.05}$ – least significant difference at the level α = 0.05

ry, the monthly sum of rainfall in June was lower by 45.5 mm than the long-term average. In 2015, the growth of winter wheat was negatively influenced by abnormal rainfall. The monthly sum of rainfall was higher by 32.5, 21.1 and 21.1 mm in January, March and April, respectively. On the contrary, the monthly sum of rainfall in June was lower by 59.0 mm than the long-term average. Weather conditions of particular years were the most important factor affecting the grain yield of winter wheat.

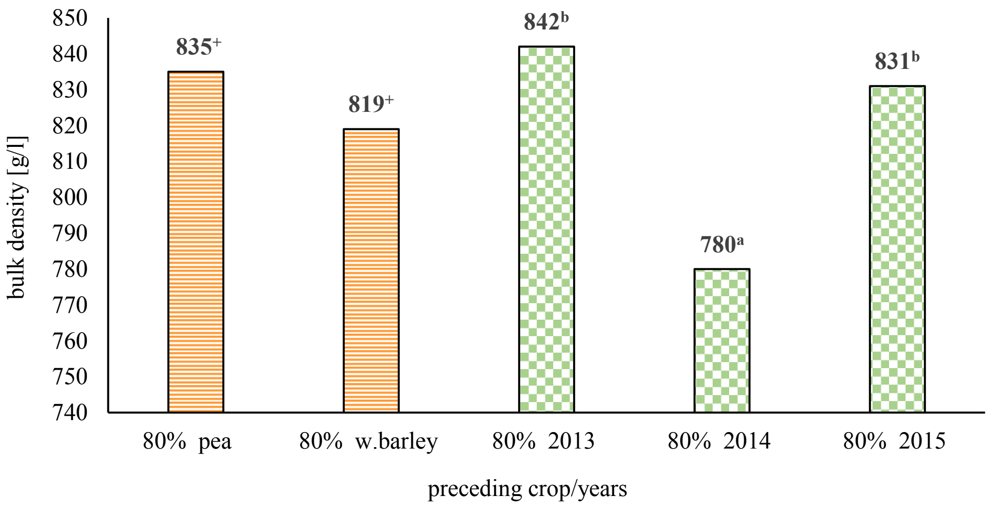
The weight of 1,000 grains of winter wheat was statistically significantly influenced by the preced-

T a b l e 5

The influence of fertilisation and share of cereals on grain yield and straw yield of winter wheat (analyse of variance)

Factor	Grain yield [t/ha]					Straw yield [t/ha]				
	df	MS	F	*P*	$LSD_{0.05}$	*df*	MS	F	*P*	$LSD_{0.05}$
Fertilisation [A]	1	3.46	9.75	+	0.35	1	6.02	2.74	–	–
PC(B)	1	11.91	33.54	+	0.35	1	14.21	6.48	+	0.87
A × B	1	0.01	0.02	–	–	1	0.01	0.00	–	–
Year (C)	2	17.61	49.59	+	0.52	2	26.27	11.97	+	1.29
A × C	2	5.24	14.77	+	0.90	2	1.18	0.54	–	–
B × C	2	2.35	6.61	+	0.90	2	6.86	3.13	–	–
Total	47	0.36	–	–	–	47	0.22	–	–	–
Error	33	1.83	–	–	–	33	3.81	–	–	–

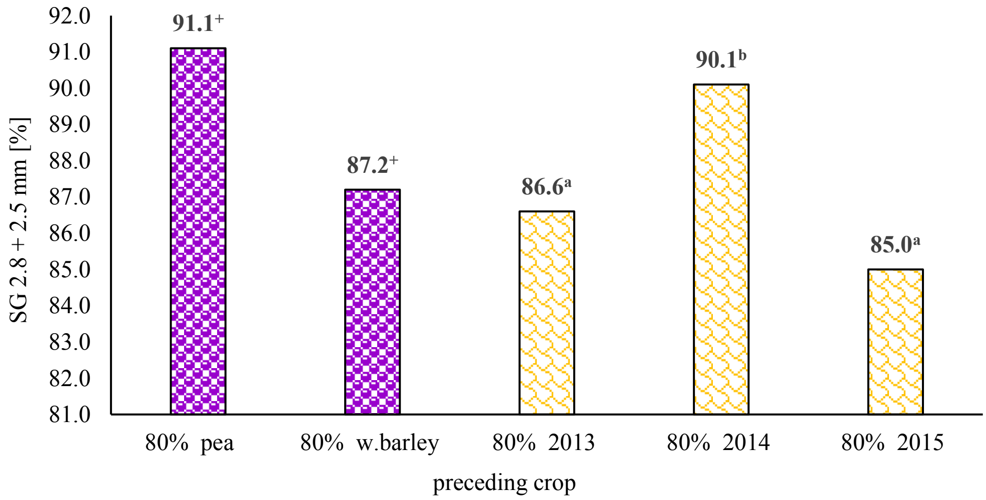
PC – preceding crop; *df* – degrees of freedom; MS – average squares, F – F-test; *P* – effect of a factor significant at the level 0.05; $LSD_{0.05}$ – least significant difference at the level α = 0.05



Average bulk density after different preceding crop – pea, w.barley – winter barley; +significant difference at the level α = 0.05. Average bulk density in years after both preceding crops – different literae – significant difference at the level α = 0.05; equal literae – insignificant difference at the level α = 0.05.

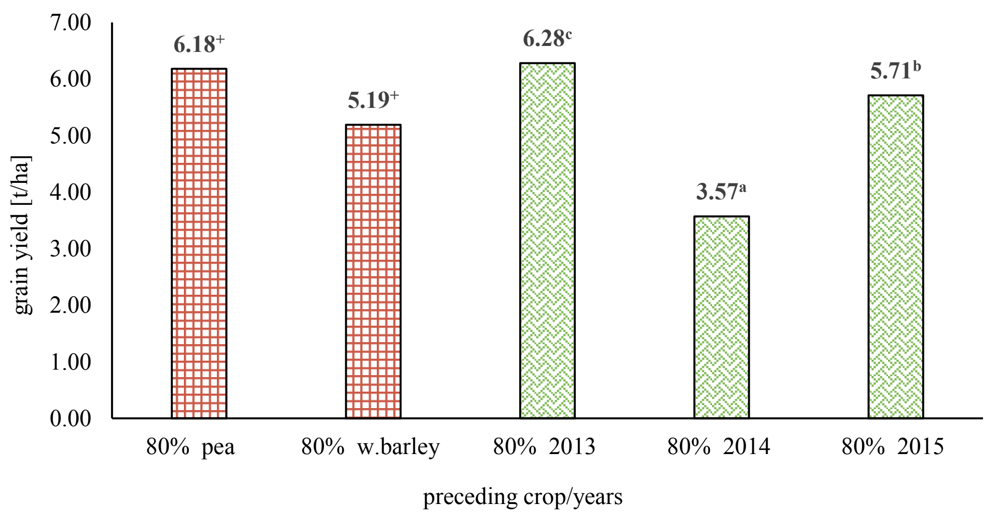
Figure 2. The bulk density [g/l] of winter wheat after field pea and winter barley in years 2013–2015

ing crop and weather in particular years (Table 3). Similarly, Jamriška *et al*. (2006) found out that nitrogen fertilisation was not effective on grain yield, but decreased values of the weight of 1,000 grains and the share of great kernels. Sieling *et al*. (2005) suggested that the yield losses due to an unfavourable preceding crop combination was mainly due to a reduced number of ears/m^2 and a decreased 1,000 grain weight. In 2014, the weight of 1,000 grains of winter wheat (Figure 1) was statistically significantly higher (49.3 g) than in 2015 (47.9 g). The weight of 1,000 grains after field pea was statisti-



Average share of grains 2.8 + 2.5 mm sieve after different preceding crop – pea; w.barley – winter barley; +significant difference at the level α = 0.05. Average share of grains 2.8 + 2.5 mm sieve in years after both preceding crops – different literae – significant difference at the level α = 0.05; equal literae – insignificant difference at the level α = 0.05.

Figure 3. The share of grains over 2.8 + 2.5 mm sieve [%] of winter wheat after field pea and winter barley in years 2013–2015



Average grain yield after different preceding crop – pea; w.barley – winter barley; +significant difference at the level α = 0.05. Average grain yield in years after both preceding crops – different literae – significant difference at the level α = 0.05; equal literae – insignificant difference at the level α = 0.05.

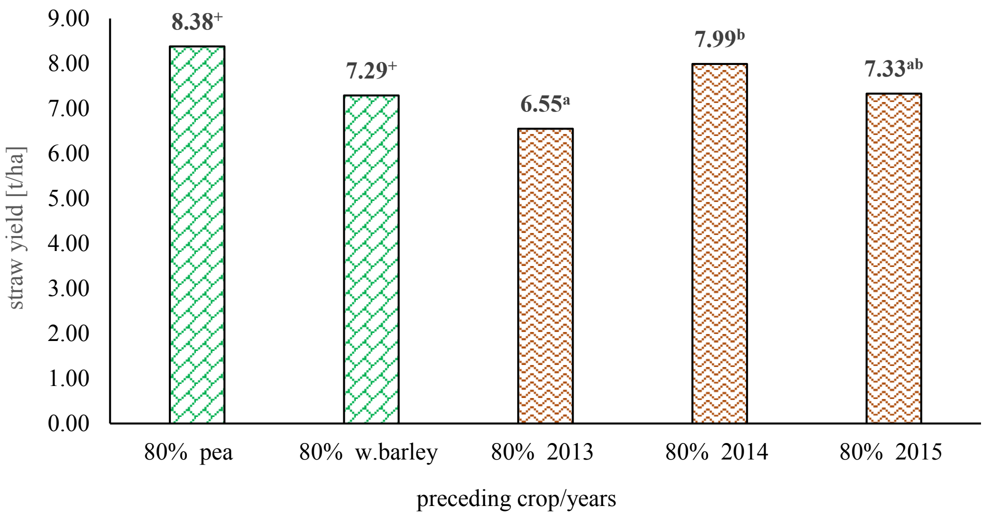
Figure 4. The grain yield [t/ha] of winter wheat after field pea and winter barley in years 2013–2015

cally significantly higher (51.2 g) than after preceding crop of winter barley (48.6 g). Sieling and Christen (2015) investigated the effects unfavourable preceding crops on the grain yield of winter oilseed rape, winter wheat and winter barley. Wheat as the preceding crop mainly decreased the 1,000 grain weight, and to a lesser extent, the ear density of the subsequent wheat crop.

The bulk density of winter wheat was statistically significantly influenced by preceding crop, weather in particular years and by interaction between the preceding crop and particular years (Table 4). The bulk density (Figure 2) after field pea was statistically significantly higher (835 g/l) than after preceding crop of winter barley (819 g/l). In 2014, the bulk density of winter wheat was statistically significantly lower (780 g/l) than in 2013 (842 g/l) and in 2015 (831 g/l).

The share of grains over 2.8 + 2.5 mm sieve of winter wheat was statistically significantly influenced by the preceding crop, weather in particular years and the interaction between fertilisation and weather in particular years (Table 4). The share of grains over 2.8 + 2.5 mm sieve (Figure 3) after field pea was statistically significantly higher (91.1%) than after preceding crop of winter barley (87.2%). In 2014, the share of grains over 2.8 + 2.5 mm sieve of winter wheat was statistically significantly higher (90.1%) than in 2013 (86.6%) and in 2015 (85.0%).

The grain yield of winter wheat was statistically significantly influenced by fertilisation, preceding crop, weather in particular years, the interaction between fertilisation and weather in particular years and the interaction between the preceding crop and weather in particular years (Table 5). The grain yield in the treatment with mineral fertilisation and organic manure Veget incorporation pea was statistically significantly higher (5.95 t/ha) than in the treatment with mineral fertilisation only (5.41 t/ha). The trend of increasing grain yield was also influenced by better crop management practices and more effective N use by the modern cultivars (Užík & Žofajová 2009). In 2014, the grain yield of winter wheat was statistically significantly lower (3.57 t/ha) than in 2013 (6.28 t/ha) and in 2015 (5.71 t/ha). In accordance with the results Užík *et al*. (2008), reasons of low grain yield in 2014 were low precipitations in June during the grain filling period. Similarly, Hudec *et al*. (2006) found out that drought stress (water deficiency) in the phase between the milk and wax grain ripeness decreased the grain



Average straw yield after different preceding crop – pea; w.barley – winter barley; +significant difference at the level α = 0.05. Average straw yield in years after both preceding crops – different literae – significant difference at the level α = 0.05; equal literae – insignificant difference at the level α = 0.05.

Figure 5. The straw yield [t/ha] of winter wheat after field pea and winter barley in years 2013–2015

yield significantly (an average by 34%), mainly as a consequence of the reduction of grain number per ear. The grain yield (Figure 4) after field pea was statistically significantly higher (6.18 t/ha) than after preceding crop of winter barley (5.19 t/ha). Stevenson (1996) found out that the inclusion of a pulse crop in rotation often leads to greater seed yields in succeeding cereal crop. Wheat seed yield was 43% greater (rotation benefit) when preceded by pea rather than wheat. Our results revealed that the increase of winter wheat grain yield after field pea in 2013–2015 was 19% in comparison with the preceding crop winter barley. In 2007–2009, the average winter wheat grain yield was 6.02 t/ha and the average winter wheat grain yield after winter barley was 4.75 t/ha. The increase in winter wheat yield after field pea cultivation was 26.74% (Babulicová *et al*. 2011). In 2010–2012, the winter wheat grain yield after field pea was at 1.22 t/ha (18%) higher than the winter wheat grain yield after winter barley (Babulicová 2014). Carr *et al*. (2008) suggested that wheat grain yield was 524 to 739 kg/ha greater in the winter wheat–field pea rotation compared with winter wheat–winter wheat rotation from 2000 to 2003, depending on the year. Similarly, Sieling and Christen (2015) suggested that unfavourable preceding crops significantly decreased the yield of winter wheat by 10% on average, however, with a large year-to-year variation. In double-cropping system, in which cereals and legumes were associated, the winter wheat yield was reduced by 50% or more in comparison with control plots (Sarunaite *et al.* 2013). Sieling *et al*. (2005) indicated that wheat following oilseed rape achieved 8 t/ha whereas wheat following wheat yielded 1 t/ha (13%) less compared with wheat after oilseed rape, due to a reduction of all yield components. Anderson (2008) found that winter wheat grain yield following oat-pea was by 28% higher than following spring wheat. The favourable impact of oat-pea on winter wheat yield may be related to suppression of root diseases (Wildermuth & McNamara 1991). Other research has shown that oat (Lockie *et al.* 1995), pea (Stevenson & Van Kessel 1996) and soybean (Vyn *et al.* 1991) can reduce disease severity in wheat. The importance of crop rotation on the grain yield and quality of wheat was confirmed by Borgi *et al*. (1995). In the wheat–maize rotation, maximum yield and quality was achieved with the highest rate of fertilisers even in the absence of manure. In the rotation that included alfalfa, maximum yield was obtained with the lowest rate of fertilisers but, to optimize quality, it appeared necessary to apply the highest rate of nitrogen (200 kg/ha). Hossain *et al*. (2016) found that the inclusion of legumes in the wheat–rice cropping sequence, particularly the use of mung bean, resulted in highest productivity. The wheat–mung bean–rice cropping system under integrated plant nutrition system with organic manure (especially 3–6 t/ha poultry manure) rendered 57% higher equivalent yield than wheat–fallow–rice rotation. Under European conditions, grain legume pre-crop effects are variable and increasing cereal yields by 0.5–1.6 t/ha (Preissel *et al*. 2015). According to the meta-analysis by Preissel *et al*. (2015), the pre-crop effect of grain legumes is highest under low N fertilisation to subsequent crops and comparable to non-leguminous oilseed crops.

The straw yield of winter wheat was statistically significantly influenced by preceding crop and weather in particular years (Table 5). The straw yield (Figure 5) after pea was statistically significantly higher (8.38 t/ha) than after the preceding crop of winter barley (7.29 t/ha). In 2013, the straw yield of winter wheat was statistically significantly lower (6.55 t/ha) than in 2014 (7.99 t/ha).

CONCLUSIONS

The weather had the strongest influence not only on the yield components but also on the grain yield and straw yield. The difference in grain yield depending upon weather in particular years was 2.71 t/ha. By including pea as the preceding crop in crop rotation with a high share of cereals, the statistically significantly increase of weight of 1,000 grains, bulk density, share of grains over 2.8 + 2.5 mm sieve, grain yield and straw yield were reached. These results suggest that preceding crop can positively influence the production potential of winter wheat despite unfavourable climatic conditions in 2013–2015. The increase of winter wheat grain yield at 0.99 t/ha was due to including pea as preceding crop of winter wheat. The results expressly confirm that despite the stress factors (e.g. irregular rainfall division in a vegetation period, increase of average monthly temperatures of air), the winter wheat grain yield can be increased to a substantial degree by the preceding crop pea and the combination of mineral and organic fertilisation.

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