WINTER BARLEY PRODUCTION IN RELATION TO CROP ROTATIONS, FERTILISATION AND WEATHER CONDITIONS

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The aim of the study was to evaluate the influence of crop rotations, fertilisation and weather conditions on the grain yield and yield components of winter barley. Long-term field experiment was situated in the area of continental climate. There were the crop rotations with 40%, 60% and 80% share of the cereals. Two treatments of fertilisation were applied: H1 and H2. In the first treatment (H1), nitrogen, phosphorus and potassium in mineral fertilisers + organic manure Veget® were applied. In the second treatment (H2), nitrogen, phosphorus and potassium were applied in fertilisers only. Winter barley cultivar Barcelona was grown in years 2010–2015. The number of spikes per 1 m², proportion of grains over sieve 2.5 + 2.8 mm and grain yield of winter barley were statistically significantly influenced by fertilisation. In the variant H1 (mineral fertilisation with addition of organic manure Veget®), the statistically higher ($P \leq 0.05$) grain yield was obtained (5.71 t/ha) than in the treatment with mineral fertilisation only (5.30 t/ha). In the year 2011, which was very unfavourable for winter barley development, the grain yield in the treatment with mineral fertilisation with the addition of organic manure Veget® was by 1.23 t/ha (32.1%) higher than that in treatment with mineral fertilisation only.

Key words: winter barley, crop rotation, fertilisation, grain yield, yield components

Nowadays, crop rotations, in general, are considered to be key sustainable practice that influences production ability and maintenance or enhancement of soil fertility in long-term view. Economic conditions are forcing farmers to look at the profit and this leads them to cereal-dominated crop rotations with increasing risk because of unfavourable preceding crops (Sieling & Christen 2015). Jensen *et al.* (2004) carried out the study to compare preceding crops lupine, pea and oat and their effects on the yield of subsequent winter barley crops. The effect of lupine on the subsequent winter barley grain yield was significantly higher than that of pea, probably due to greater N-root nitrogen residues. Besides the balanced crop rotation, successful growth of winter barley is supported by balanced fertilisation. Sieling *et al.* (2014) compared the utilisation of nitrogen

from slurries and from mineral fertilisers. In plots without N fertilisation, oilseed rape showed no yield trends during the experimental period, whereas wheat (barley) yield started to decrease after 10 (13) years without N fertilisation. Possibilities of the application of organic-mineral fertilisers in various forms and their importance for yield stabilisation are investigated. Studies dealing with winter barley nutrition, in general, report about controlled nutrition based on soil analyses of the phosphorus and potassium and on soil and plant analyses of the nitrogen (Molnárová *et al.* 2012). Organic manure is the source of organic matter and nutrients. However, these nutrients are gradually released and it takes time to integrate them back to the soil–plant system. Fertilisers provide nutrients that can be relatively quickly absorbed by plants, leading to the develop-

ment of a rich root system and thus higher yields under good weather conditions (Hejman *et al.* 2012). In dry seasons, the mineralisation of fertiliser is decreased, and in wet seasons when the soil moisture is near the field capacity, the mineralisation is increased (Cassman & Munns 1980). Whilst regular application of high rates of mineral nutrients can provide high yields and leave a relatively good pool of nutrients in the soil, organic manure release more nutrients (N, P, K, Ca, Mg and others) in smaller amount and for a longer period. Thus combined application of mineral fertiliser with nitrogen, phosphorus, potassium (NPK) and farmyard manure (FYM) provides a wide range of nutrients that are released in both short and long period and reduces the negative effect of mineral fertiliser NPK on topsoil pH (Hlisnikovský & Kunzová 2014).

Winter barley has a rapid initial growth and good nutrients utilisation. The differences in dissimilar grain yield development between wheat and barley are explained by the different efficiency of nitrogen and water utilisation (Cossani *et al.* 2012). Barczak (2008) took samples from winter barley in five growth stages from the tillering to ripening: tillering, stem elongation, heading, grain filling and wax ripening. The results revealed that the content of N, P, K, Ca, Mg and Na in the above ground biomass of winter barley decreased in subsequent phenological stages from tillering up to wax ripening. In general, nitrogen had a positive effect on the content of monitored microelements in the above ground biomass of winter barley in all growth stages. Charles *et al.* (2012) compared two-row and six-row varieties of winter barley. They found out that higher grain yield of six-row variety was caused by producing a higher number of grains in spike. The better tillering and higher weight of grain in the two-row variety were not able to compensate the higher number of grains in spike in the six-row variety. Two-row variety showed higher protein, fat and mineral substances in grain. These parameters were influenced by nitrogen fertilisation.

The objective of this study was to evaluate the effect of two different crop rotations, fertilisation and climate conditions in years 2010–2015 on the number of spikes per square metre, bulk density of grains, 1,000 grains' weight, the proportion of grain higher fractions (2.8 + 2.5 mm) and grain yield of winter barley.

MATERIAL AND METHODS

The presented results are part of a long-term field experiment established in 1974 in the maize-barley-producing area at the Experimental Station Borovce, belonging to the National Agricultural and Food Centre – Research Institute of Plant Production. The experimental fields at Borovce are located at an elevation of 167 m a.s.l. The region is characterised by continental climate with average annual rainfall of 593 mm (from 358 mm during the vegetation period) and long-term average annual temperature of 9.2°C (15.5°C during the vegetation season). The climatic conditions in Borovce are presented in Tables 1 and 2. The soil characteristics of field plots were as follows: Luvi-haplic Chernozem. The depth of the topsoil layer was 24–28 cm. The content of nutrients in the soil is given in Tables 3 and 4 (the analysis was according to Mehlich II). The rates of nutrients applied in fertilisers are in Tables 5 and 6. Conventional ploughing to a depth of 22–25 cm, sowing, fertilisation and plant treatments were performed according to the recommendations for the given area (the term of sowing: at least 10th of October; sowing rate: 450 seeds/1 m²). The pesticides were used according to the actual occurrence of diseases, pests and weeds. The winter barley was grown in crop rotations with 60% and 80% proportion of cereals (Table 7). In both crop rotations, the preceding crop of winter barley was winter wheat. In crop rotations, two different fertilisation of winter barley were used: H1 – mineral fertilisation + organic manure Veget®; H2 – only fertiliser amendment. The mineral fertilisation consisted of N, P and K, application rates of P and K was calculated according to the balance methodology (Bizík *et al.* 1998). Veget® was applied at a dose of 5 tons/ha/year. The composition of organic manure Veget® was as follows: dry matter content minimum, 85% (includes combustible matter content 75%); total N content, 2.5–3.0%; total P₂O₅ content, 0.5–2.0%; K₂O content, 1.5%; C:N ratio, 13:1; and pH (in water), 8.5. Total N rates applied to winter barley were split to basic fertilisation – in autumn before sowing and regenerative fertilising – very soon in spring. In the experimental years 2010–2015, the winter barley cv. Barcelona (double row cultivar) was used.

T a b l e 1

Weather conditions in the experimental years 2010–2012 on the stand Borovce

Month	n (1951–1980)		2010		2011		2012	
	x_{id} [°C]	Σ [mm]	x_{id} [°C]	Σ [mm]	x_{id} [°C]	Σ [mm]	x_{id} [°C]	Σ [mm]
January	−1.8	32	2.22	60.6	−1.87	32.4	−0.48	78.8
February	0.2	33	1.39	38.0	−2.06	8.0	−4.59	39.2
March	4.2	32	4.82	19.5	4.31	29.0	5.07	4.5
April	9.4	43	9.91	65.0	11.6	30.4	9.07	20.3
May	14.1	54	15.41	168.3	14.68	93.2	15.43	16.2
June	17.7	80	19.47	95.0	19.15	165.2	18.88	108.1
July	18.9	76	23.02	98.0	18.14	83.2	20.73	94.1
August	18.4	68	19.65	99.5	20.48	25.4	20.12	10.6
September	14.5	38	13.42	101.5	16.41	17.8	14.76	41.5
October	9.6	42	8.04	25.0	7.77	32.9	8.02	88.5
November	4.6	51	7.36	76.0	1.37	2.0	4.88	22.6
December	0.3	46	−2.23	48.8	0.03	42.4	−2.81	46.5
x_{id} [°C]	9.2	–	9.84	–	9.17	–	9.09	–
Σ [mm]	–	595	–	895.2	–	561.9	–	570.9

N – long-term (30-year) normal; x_{id} – average air temperature; Σ – sum of precipitation

T a b l e 2

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

Month	n (1951–1980)		2013		2014		2015	
	x_{id} [°C]	Σ [mm]	x_{id} [°C]	Σ [mm]	x_{id} [°C]	Σ [mm]	x_{id} [°C]	Σ [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_{id} [°C]	9.2	–	8.47	–	9.40	–	9.05	–
Σ [mm]	–	595	–	680.4	–	720.3	–	557.7

N – long-term (30-year) normal; x_{id} – average air temperature; Σ – sum of precipitation

T a b l e 3

The content of nutrients in soils of experimental field plots during the seasons 2009–2012
(analyses in autumn)

SC	2009/2010			2010/2011			2011/2012		
	P	K	Nan	P	K	Nan	P	K	Nan
	[mg/kg]								
60% H1	112	365	9.13	65	227	6.54	142	308	6.19
60% H2	128	361	8.22	69	230	6.82	137	315	7.05
80% H1	86	335	6.23	102	204	5.96	67	218	2.53
80% H2	91	340	7.18	108	201	5.71	59	221	3.47

SC – share of cereals in crop rotation; Nan – $\text{NH}_4^+ + \text{NO}_3^-$

T a b l e 4

The content of nutrients in soils of experimental field plots during the seasons 2012–2015
(analyses in autumn)

SC	2012/2013			2013/2014			2014/2015		
	P	K	Nan	P	K	Nan	P	K	Nan
	[mg/kg]								
60% H1	137	301	15.17	169	312	13.1	136	316	8.73
60% H2	134	306	14.85	175	319	15.2	123	307	8.27
80% H1	91	247	11.91	94	248	12.3	129	342	6.29
80% H2	85	241	12.07	82	254	11.2	95	298	6.78

SC – share of cereals in crop rotation; Nan – $\text{NH}_4^+ + \text{NO}_3^-$

T a b l e 5

Rates of nutrients: nitrogen (N), phosphorus (P) and potassium (K) in 2009–2012

SC	2009/2010				2010/2011				2011/2012			
	Autumn			Spring	Autumn			Spring	Autumn			Spring
	P	K	N	N	P	K	N	N	P	K	N	N
	[kg/ha]											
60% H1	0	0	30	50	0	110	35	50	0	0	30	50
60% H2	0	0	30	50	0	120	35	50	0	0	30	50
80% H1	30	0	35	50	30	110	35	50	35	110	35	50
80% H2	30	0	35	50	30	120	35	50	35	120	35	50

SC – share of cereals in crop rotation

T a b l e 6

Doses of nutrients: nitrogen (N), phosphorus (P) and potassium (K) in 2012–2015

SC	2012/2013				2013/2014				2014/2015			
	Autumn			Spring	Autumn			Spring	Autumn			Spring
	P	K	N	N	P	K	N	N	P	K	N	N
	[kg/ha]											
60% H1	0	0	0	50	0	0	0	50	0	0	30	50
60% H2	0	0	0	50	0	0	0	50	0	0	30	50
80% H1	30	110	15	50	30	110	0	50	0	0	35	50
80% H2	30	120	15	50	30	120	15	50	30	120	35	50

SC – share of cereals in crop rotation

In this work, the bulk density of grains, 1,000 grain's weight, number of spikes per square meter, the proportion of grains over sieve 2.5 + 2.8 mm and grain yield were evaluated.

The statistical significance of the data was computed by multiple-way analysis of variance (ANOVA). In addition, the least significant difference (*LSD*) multiple range test was used to determine which means differed significantly from the others, using a significance level of 0.05%. These analyses were performed using Statistica 6.1. (StatSoft Inc., Tulsa, USA).

RESULTS AND DISCUSSION

The years 2010–2015 were extreme in term of average daily temperatures and monthly sums of rainfall (Tables 1 and 2). In the years 2010–2015, the average daily temperatures were increase in

June by 0.9°C and in July by 1.9°C in comparison to the long-term average. In 2010–2015, monthly sum of rainfall in May exceeded long-term average by 32 mm. The increase in monthly sum of rainfall in comparison with long-term average was 114.3 mm in May 2010 39.2 mm in May 2011 and 85.2 mm in June 2011; 43.3 mm in March 2013 and 56.3 mm in May 2014. The weather in the individual years influenced the production ability of winter barley in the biggest measure. The proportion of cereals in crop rotations has no statistically significant influence on yield components and grain yield of winter barley. The combination of mineral fertilisers with organic manure influenced the grain yield and yield components of winter barley in considerable extent, particularly under unfavourable weather conditions in 2011 (exceed of precipitation in May and June; high temperature in April), 2013 (lack of precipitation in April) and 2015 (lack of precipitation in April and June).

The bulk density and 1,000 grains' weight were statistically significantly influenced by weather in particular years and interaction between fertilisation and years. In year 2011, the bulk density was statistically lower (651 g/l) than that in 2010, 2012, 2013 and 2015 (Figure 1, Table 8). In year 2011, 1,000 grains' weight was statistically lower (47.5 g) than that in 2010, 2012, 2013, 2014 and 2015 (Figure 2, Table 8). Sieling and Christen (2015) reported that 1,000 grains' weight was decreased by unsuitable preceding crop (wheat).

Weather in particular years and fertilisation had a statistically significant influence on the number of

T a b l e 7

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

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

spikes per 1 m². In year 2013, the number of spikes per 1 m² was statistically significantly higher (745 pcs/m²) than that in 2010, 2011, 2012 and 2015 (Figure 3, Table 8). In the treatment with mineral fertilisers and organic manure Veget® incorporation, the number of spikes (Table 9) was statistically higher (630 pcs/m²) than in the treatment with mineral fertilisation only (557 pcs/m²).

The proportion of grains 2.8 + 2.5 mm of winter barley was statistically significantly influenced by weather in particular years, fertilisation and interaction between fertilisation and years. The share of grains 2.8 + 2.5 mm was statistically higher in 2010 (63.0%) and 2015 (63.6%) than in 2011, 2012, 2013 and 2014 (Figure 4, Table 8). In the treatment with mineral fertilisers and organic manure Veget®, the

Figure 1. The bulk density [g/l] of winter barley in crop rotations

T a b l e 8

Average values of grain yield and yield components in years 2010–2015

Years	BD [g/l]	OTGW [g]	NS [pcs/m ²]	PGOS [%]	GY [t/ha]
2010	702 ^b	50.4 ^b	582 ^{ab}	63.0 ^b	5.76 ^b
2011	651 ^a	47.5 ^a	497 ^a	52.1 ^a	4.44 ^a
2012	701 ^b	52.0 ^c	426 ^a	52.1 ^a	4.56 ^a
2013	694 ^b	51.1 ^{bc}	745 ^{bc}	51.1 ^a	5.93 ^b
2014	697 ^b	49.3 ^{bd}	677 ^b	50.5 ^a	5.69 ^b
2015	711 ^c	50.1 ^b	632 ^{bd}	63.6 ^b	6.63 ^c
Average	693	50.1	593	55.4	5.50
LSD _{0.05}	8.86	1.51	103.71	7.74	0.53

BD – bulk density; OTGW – 1,000 grains' weight; NS – number of spikes; PGOS – proportion of grains over sieve; GY – grain yield

The identical characters or identical group of characters (e.g. bc, bc) mean that there are no statistically significant differences. The different characters or different group of characters (e.g. bc, bd) mean that there are statistically significant differences. If there is identical characters in the group of characters with singly located character (e.g. a, ab or b, bc), there are no statistically significant differences.

share of grains 2.8 + 2.5 mm was statistically higher (58.8%) than that in the treatment with mineral fertilisation only (52.1%) – Table 9.

The grain yield of winter barley was statistically significantly influenced by fertilisation, years and interaction between fertilisation and years. The grain yield was statistically lower in 2011 (4.44 t/ha) and 2012 (4.56 t/ha) than in 2010, 2013, 2014 and 2015 (Figure 5, Table 8). In the treatment with fertilisers and organic manure Veget®, the grain yield was statistically higher (5.71 t/ha) than that in the treatment with mineral fertilisation only (5.30 t/ha) – Table 9. A positive effect of organic manure Veget® on number of ears, share of grain 2.8 + 2.5 explained the increase in winter barley grain yield across ex-

perimental years and treatments. In 2010–2015, the difference between average grain yield because of the different fertilisation was 7.7%.

Kismanyoky and Toth (2013) reported that depending on the type of crop, the specific year and the N content in the soil, with combined application of mineral fertilisers and organic manure, resulted in a 12–17% increase of crop yield. In our experiment in 2011, the increase in winter barley grain yield in the treatment with mineral fertilisers and organic manure Veget® incorporation was by 32.1% higher than that in the treatment with mineral fertilisation only.

In accordance with our results, Hernández *et al.* (2013) found out that the nitrogen content in the soil

Figure 2. The 1,000 grains' weight [g] of winter barley in crop rotations

T a b l e 9

Average values of grain yield and yield components in two fertilisation treatments

Fertilisation	NS [pcs/m ²]	PGOS [%]	GY [t/ha]
H1	630 ^a	52.1 ^a	5.71 ^a
H2	557 ^b	58.8 ^b	5.30 ^b
Average	557	55.5	5.51
<i>LSD</i> _{0.05}	40.7	3.04	0.21

NS – number of spikes; PGOS – proportion of grains over sieve; GY – grain yield

The identical characters mean that there are no statistically significant differences. The different characters mean that there are statistically significant differences.

Figure 3. The number of spikes on 1 m² [pcs/m²] of winter barley in crop rotations

Figure 4. The grain over sieve 2.5 mm [%] of winter barley grain in crop rotations

Figure 5. The grain yield [t/ha] of winter barley in crop rotations

for the plants was higher in the treatment with annual pig dung application in comparison with the treatment with mineral fertilisation only or in comparison with untreated plot. These differences were clearly evident in dry years. Plaza-Bonilla *et al.* (2017) found out that for a given N rate (0; 75 kg N/ha; 150 kg N/ha), the use of organic fertilisation significantly increased the water use efficiency in both tillage methods (conventional tillage and no-tillage). Hlisenikovsky and Kunzová (2014) reported the results from the long-term field experiment. The field experiment was established in 1954. The effect of six fertiliser treatment on a topsoil pool of nutrient content, organic carbon content (Cox) and pH was evaluated between the years 2001 and 2012. The highest yields were reached in the treatment with the NPK + FYM fertilisation. The application of organic manure, without any mineral fertilisers, cannot provide a sufficient amount of nutrients to create high yields and increase the soil nutrient pool for the next arable crops. Kovacevic *et al.* (2009) investigated the influence of different fertilisation treatments on the grain yield of corn, winter wheat and winter barley. The grain yield of winter barley was increased by 19% in the treatment with higher doses of phosphorus and potassium.

Our results revealed that the increase in grain yield in 2015 was caused mainly by statistically significantly higher number of spikes and the proportion of grains 2.8 + 2.5 mm of winter barley in the treatment with fertilisers and organic manure Veget® incorporation.

Charles *et al.* (2012) emphasised the dependence of winter barley grain yield on increasing fertilisation rates under favourable growing conditions, especially during the period with sufficient amount of accessible water. According to Albrizio *et al.* (2010), water availability enhances N absorption: the response of barley to N fertilisation was higher in the year with better water availability during the most sensitive stages to drought stress. Cantero-Martinez *et al.* (1995) claimed that in very dry year, the higher rate of N fertilisation depressed the yield. Nitrogen fertilisation in very dry season increased green area index and nitrogen uptake by the plant but did not affect any yield component.

In years 2010–2015, we observed an increasing frequency of extreme weather events such as excess

of precipitation, lack of precipitation or high temperature. Therefore, searching for arrangements to mitigation of negative impact on the grain yield and yield components is needed. Fernández-Getino *et al.* (2015) estimated the influence of rainfall and temperature on barley yield parameters in different crop and tillage systems. Regarding the influence of previous crop on barley yield, vetch and fallow favourably influenced the winter barley grain yield. The analysis of barley components with minimum tillage and no tillage did not show significant differences compared to conventional tillage. De Vita *et al.* (2017) found that reduced inter-row distance dramatically reduced weed biomass and increased wheat yield and nitrogen uptake. An agronomic improvement in grain yield and quality of winter wheat could be obtained through the application of strategies, such as application foliar fungicides or fertilisers. These treatments protect health of the last leaves and delay the senescence process during ripening (Marinaccio *et al.* 2015).

CONCLUSIONS

The climate in the period 2010–2015 was the strongest factor influencing the grain yield and yield components of winter barley. The differences in grain yields of winter barley depending on the weather in particular years reached 2.19 t/ha (49.3%). Fertilisation is another very important factor influencing the production ability of winter barley. In years 2010–2015, the average grain yield of winter barley in the treatment with mineral fertilisers and organic manure Veget® incorporation was 0.41 t/ha (7.7%), which was higher than that in treatment with mineral fertilisers only. Increasing frequency of extreme weather events such as excessive rainfall and prolonged droughts has been observed. Our study confirmed that the application of organic manure contributes to winter barley yields stabilisation. That was manifested most clearly in year 2011. In this year, the difference in grain yield of winter barley in the treatment with mineral fertilisation and organic manure incorporation was 1.23 t/ha (32.1%), which was higher than that in the treatment with fertilisers only.

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