# The influence of fertilization and crop rotation on the winter wheat production

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**ABSTRACT**

In a long-term field experiment winter wheat was grown in crop rotations with 40, 60 and 80% proportion of cereals. Two levels of fertilization were used: $H_1$ – mineral fertilization N, P, K + organic fertilization Veget®; $H_2$ – only mineral fertilization N, P, K. Winter what was grown after two preceding crops: pea and winter barley. In 2010–2012 the grain yield of winter wheat after pea was statistically higher at fertilization with mineral fertilizers N, P, K and organic manure Veget® (7.15 t/ha) in comparison with mineral fertilizers only (6.65 t/ha). In crop rotation with 80% of cereals the grain yield of winter wheat after pea as a preceding crop was statistically higher (6.81 t/ha) than after winter barley (5.59 t/ha). The rising of grain yield at 1.9 t/ha was achieved by suitable preceding crop (pea) and by combined fertilization (mineral fertilizers N, P, K + organic manure Veget®). The grain yield of winter wheat 5.24 t was obtained by mineral fertilization N, P, K only and after winter barley. By mineral fertilization N, P, K + organic manure Veget®) and after pea as a preceding crop the grain yield of winter wheat 7.14 t/ha was reached.

**Keywords**: crop rotation; *Triticum aestivum*; proportion of cereals; grain yield; bulk weight

In agricultural production the crop rotations are always one of the principal agrotechnical measures which contribute to increased crop production. From foreign and national literature it follows that farms use high proportion of cereals and the proportion of root crops decreases. In crop rotations they use the cereals after cereals, in better case after oil crops. By a higher proportion of cereals the decrease of grain yield is expected. In general, the reasons of grain yield decrease lie in the damage caused by fungal diseases, stronger weed infestation rate, the degradation of soil structure and in negative impacts on the water and air regime. Other reasons include the worse balance of humus in the soil and the nutrient-supply. According to Khosro et al. (2011) cropping systems in Iran farmland areas are characterized by continuous cultivation of crops with consumption of chemical fertilizer leading to serious soil erosion and fertility decline. The disrupted balance of agro-ecosystem can be compensated by rotation of crops with various requests on the nutrients. We can keep the stability of agrosystem by using adequate input of organic and mineral fertilisers as well as by using the suitable applications of pesticides. The efficiency of nitrogen fertilization is evaluated most often with respect to the amount of qualitative changes in grain yield. However, a thorough evaluation of the results of fertilization requires a wider approach (Kolodziejczyk et al. 2013). Engström and Bergkvist (2009) in their the study quantified the effect of three N fertilization strategies on the number of tillers at growth stage (GS) 30–31 and the grain yield of winter wheat. They suggested the N application before growth stage 30 to avoid yield reductions. Kato and Yamagistri (2011) investigated the growth response of winter wheat to different fertilization regimes in long-term experiments. Varieties of winter wheat were grown crop rotation with maize with a high rate of organic manure, and standard or low rates of inorganic fertilizer for 3 years. In spite of significantly higher grain yield in crop rotation with high dose of organic manure, the dry matter partitioning during the grain-filling period resulted in an imbalance in the sink-source relationship in organic manure: the number of

Table 1. Weather conditions in 2010–2012 in the experimental station Borovce (belonging to National Agricultural and Food Centre Lužianky – Research Institute of Plant Production Piešťany) in comparison with long-term average

| Month | Long-term average (1951–1980) | | 2010 | | 2011 | | 2012 | |
|---|---|---|---|---|---|---|---|---|
| | $x_{td}$ | $\Sigma_z$ | $x_{td}$ | $\Sigma_z$ | $x_{td}$ | $\Sigma_z$ | $x_{td}$ | $\Sigma_z$ |
| 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 | 11.60 | 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 |
| $x_{td}$ | 9.2 | | 9.84 | | 9.17 | | 9.09 | |
| $\Sigma_z$ | | 595 | | 895.2 | | 561.9 | | 570.9 |

$x_{td}$ – average air temperature (°C); $\Sigma_z$ – sum of precipitation (mm)

grains was too large for the assimilation rate. The growth pattern of wheat under intensive manure application should be modified to favour biomass production during the post-anthesis stages.

## 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 Lužianky – Research Institute of Plant Production Piešťany, Slovak Republic. The experimental fields at Borovce are located at elevation of 167 m a.s.l. The region is characterized by continental climate with average annual rainfall of 593 mm (from it 358 mm during the vegetation period), and long-term average annual temperature of 9.2°C (15.5°C during the vegetation season). The weather conditions in Borovce are presented in Table 1. The soil characteristics of field plots were as follows: Luvi-Haplic Chernozem. The depth of plow layer was 24–28 cm. The soil was characterized by low content of phosphorus, good content of potassium, high content of magnesium (the analysis according to Mehlich II). Conventional ploughing to depth 22–25 cm, sowing, fertilization and plant treatments were performed according to the recommendations for the given area. The pesticide treatments were realized according to the actual occurrence of diseases, pests and weeds. The long-term field experiment in Borovce consists of three crop rotations with 40, 60 and 80% proportion of cereals (Table 2). In crop rotations two different fertilization treatments of winter wheat were used: $H_1$ – mineral fertilization + organic fertilizer (Veget®); $H_2$ – mineral fertilizer amendment. The mineral fertilization consisted of N, P and K, application at P and K dosages calculated according to the balance methodology (Bizík et al. 1998), and by the methodology of Ložek (1998). Veget® was applied at a dose of 5 t/ha/year. The composition of organic fertilizer Veget® is as follows: dry matter content min. 85% (includes

Table 2. Crop rotations with 40, 60 and 80% proportion of cereals

| | Proportion of cereals (%) | | |
|---|---|---|---|
| | 40 | 60 | 80 |
| 1 | peas | peas | winter wheat |
| 2 | winter wheat | winter wheat | spring barley |
| 3 | maize on silage | winter barley | peas |
| 4 | spring barley | maize on silage | winter wheat |
| 5 | grain maize | spring barley | winter barley |

Table 3. Doses of nutrients (kg/ha): nitrogen (N), phosphorus (P) and potassium (K) by fertilization levels in crop rotations with 40, 60 and 80% proportion of cereals

| Proportion of cereals | Preceding crop | 2009/2010 | | | 2010/2011 | | | 2011/2013 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | N | P | K | N | P | K |
| 40 $H_1$ | peas | – | – | 27 | – | – | 27 | – | – | 27 |
| 40 $H_2$ | peas | 120 | 30 | 100 | 120 | – | 100 | 120 | – | 100 |
| 60 $H_1$ | peas | – | – | 27 | – | – | 27 | – | – | – |
| 60 $H_2$ | peas | 135 | 30 | 100 | 135 | 30 | 100 | 135 | – | – |
| 80 $H_1$ | peas | – | – | 27 | – | – | 47 | – | – | 27 |
| 80 $H_2$ | peas | 135 | 30 | 100 | 135 | 30 | 120 | 135 | 25 | 100 |
| 80 $H_1$ | winter barley | – | – | 27 | – | – | 47 | – | – | 27 |
| 80 $H_2$ | winter barley | 135 | 30 | 100 | 135 | 30 | 120 | 135 | 25 | 100 |

$H_1$ – mineral fertilization N, P, K + organic fertilization Veget®; $H_2$ – only mineral fertilization N, P, K

combustible matter content 75%); total N content 2.5–3.0%; total $P_2O_5$ content 0.5–2.0%, and $K_2O$ content 1.5%, ratio C:N 13:1, and pH (in water) 8.5. Doses of N applied to winter wheat were divided: (a) basic fertilization – in autumn before sowing; (b) regenerative additional fertilising – very soon in spring; (c) productive additional fertilising was realised in growth stage of crop BBCH 32. In the experimental years 2010–2012 the winter wheat cv. Petrana was included in crop rotations.

In this work, we evaluated the number of ears per square meter, the bulk weight, the one-thousand grain weight, the grain over sieve 2.5 mm and the grain yield of winter wheat.

The statistical significance of the data was computed by multiple-way analysis of variance (ANOVA). In addition, the *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 proportion of cereals and the climatic conditions of particular years had a statistically significant influence on the number of ears of winter wheat (Table 4). In crop rotation with 80% share of cereals after peas (Table 5) the number of ears pre one square meter (573 pieces/$m^2$) was significantly lower than in crop rotation with 40% (606 pieces/$m^2$) and 60% proportion of cereals (627 pieces/$m^2$).

The climatic conditions of particular year, interaction between fertilization and years, and interaction between proportion of cereals and years had a statistically significant influence on the bulk weight of winter wheat (Table 4). In crop rotation with 80% proportion of cereals after peas as a preceding crop (Tables 5 and 6) the bulk weight was statistically higher (817 g/L) than after winter barley (796 g/L). The proportion of cereals and the climatic conditions of particular year had a statistically significant influence on the weight of one-thousand grains of winter wheat (Table 4). In crop rotation with 40% proportion of cereals (Table 5) the weight of one-thousand grains was significantly higher (41.9 g) than in crop rotation with 80% share of cereals after peas as a preceding crop (41.3 g). After preceding crop peas (Tables 5 and 6) the weight of one-thousand grains was statistically higher (41.3 g) than after winter barley (38.5 g). The climatic conditions of particular years had a statistically significant influence on the proportion of grains 2.8 + 2.5 mm of winter wheat (Table 4). After peas (Tables 5 and 6) the proportion of grains 2.8 + 2.5 was statistically higher (78.0%) than after winter barley (68.7%). In accordance with the results of Grzebisz (1988) the highest grain yield was recorded in crop rotation with 60% proportion of cereals (6.99 t/ha). Grzebisz indicated that the cultivation of winter wheat in rotation containing more than 50% cereals affected the drop of winter wheat grain yield, which was especially high on the plots without nitrogen fertilization or with low N level. The fertilization, climatic conditions of particular year, and the interaction between fertilization and years had a statistically significant influence on the grain yield of winter wheat (Table 4). When mineral fertilization and incorporation of organic fertilizer Veget® was applied (Table 6), we obtained a sig-

Table 4. The influence of fertilization and the proportion of cereals and preceding crop on yield formation elements and the grain yield of winter wheat (abbreviated analysis of variance)

| Factor | NE | | BW | | WTG | | PG | | Grain yield | |
|---|---|---|---|---|---|---|---|---|---|---|
| | sign. | $LSD_{0.05}$ | sign. | $LSD_{0.05}$ | sign. | $LSD_{0.05}$ | sign. | $LSD_{0.05}$ | sign. | $LSD_{0.05}$ |
| **Proportion of cereals** | | | | | | | | | | |
| Fertilization (A) | | 30.4 | | 1.90 | | 0.41 | | 1.17 | * | 0.14 |
| Proportion of cereals (B) | * | 44.8 | | 2.81 | * | 0.60 | | 1.73 | | 0.20 |
| A × B | | 77.8 | | 4.87 | | 1.05 | | 3.01 | | 0.35 |
| Years (C) | * | 44.8 | * | 2.80 | * | 0.60 | * | 1.73 | * | 0.20 |
| A × C | | 77.8 | * | 4.87 | | 1.05 | | 3.01 | * | 0.35 |
| B × C | | 104.3 | * | 6.52 | | 1.40 | | 4.03 | | 0.47 |
| **Preceding crop** | | | | | | | | | | |
| Fertilization | | 45.23 | | 5.44 | | 0.79 | | 2.96 | * | 0.27 |
| Preceding crop | | 45.23 | * | 5.44 | * | 0.79 | * | 2.96 | * | 0.27 |
| A × B | | 85.06 | | 4.87 | | 1.49 | | 5.57 | | 0.51 |
| Years | * | 66.82 | * | 8.03 | * | 1.17 | * | 4.38 | * | 0.40 |
| A × C | | 116.49 | | 14.00 | | 2.05 | * | 7.63 | | 0.70 |
| B × C | | 116.49 | * | 14.00 | * | 2.05 | * | 7.63 | * | 0.70 |

Sign. – signification (*$P \leq 0.05$). NE – number of ears; BW – bulk weight; WTG – weight of one-thousand grains; PG – proportion of grains 2.8 + 2.5 mm

nificantly higher grain yield after peas (7.15 t/ha) than in comparison with the mineral fertilization (6.65 t/ha). These results are in accordance with the results of Koenig et al. (2011). Biosolids in dose 0 to 1400 kg/ha results in higher grain yields (0% to 47%) than inorganic N. The appropriate application rate of nitrogen on a high-yielding wheat field was 96–168 kg N/ha. A little difference was noticed in doses of 150–200 kg N/ha. The excessive N application (above 240 kg N/ha) also obviously decreased the grain yield and N uptake efficiency. Dry matter and grain N content were influenced by the type and amount of fertilizer-N, too (Doltra et al. 2011, Wang et al. 2011, Mocanu et al. 2012).

Table 5. The yield produced elements of winter wheat in crop rotations (average in 2010–2012)

| Proportion of cereals (%) | Fertilization | Preceding crop | NE (pieces/m$^2$) | BW (g/L) | WTG (g) | PG (%) |
|---|---|---|---|---|---|---|
| 40 | $H_1$ | peas | 583 | 817 | 41.8 | 77.5 |
| | $H_2$ | | 629 | 816 | 42.1 | 78.7 |
| Average | | | 606 | 816 | 41.9 | 78.1 |
| 60 | $H_1$ | peas | 630 | 817 | 41.6 | 77.6 |
| | $H_2$ | | 623 | 818 | 41.9 | 78.1 |
| Average | | | 627 | 818 | 41.7 | 77.8 |
| 80 | $H_1$ | peas | 577 | 817 | 41.1 | 77.2 |
| | $H_2$ | | 569 | 817 | 41.4 | 78.8 |
| Average | | | 573 | 817 | 41.3 | 78.0 |
| 80 | $H_1$ | winter | 571 | 795 | 37.8 | 68.1 |
| | $H_2$ | barley | 576 | 797 | 39.1 | 69.3 |
| Average | | | 574 | 796 | 38.5 | 68.7 |
| Total average | | | 595 | 812 | 40.9 | 75.6 |

NE – number of ears; BW – bulk weight; WTG – weight of one-thousand grains; PG – proportion of grains 2.8 + 2.5 mm; $H_1$ – mineral fertilization N, P, K + organic fertilization Veget®; $H_2$ – only mineral fertilization N, P, K

Table 6. The grain yield (t/ha) of winter wheat in crop rotations

| Proportion of cereals (%) | Fertilization | Preceding crop | Grain yield 2010 | 2011 | 2012 | average |
|---|---|---|---|---|---|---|
| 40 | $H_1$ | peas | 7.09 | 8.29 | 5.90 | 7.09 |
| | $H_2$ | | 7.07 | 7.29 | 5.67 | 6.68 |
| Average | | | 7.08 | 7.79 | 5.79 | 6.89 |
| 60 | $H_1$ | peas | 7.30 | 8.28 | 6.09 | 7.22 |
| | $H_2$ | | 7.19 | 7.25 | 5.86 | 6.77 |
| Average | | | 7.24 | 7.77 | 5.97 | 6.99 |
| 80 | $H_1$ | peas | 7.42 | 8.24 | 5.76 | 7.14 |
| | $H_2$ | | 7.20 | 6.88 | 5.38 | 6.49 |
| Average | | | 7.31 | 7.56 | 5.57 | 6.81 |
| 80 | $H_1$ | winter | 5.64 | 6.93 | 5.24 | 5.93 |
| | $H_2$ | barley | 5.09 | 5.99 | 4.65 | 5.24 |
| Average | | | 5.36 | 6.46 | 4.94 | 5.59 |
| Total average | | | 6.75 | 7.39 | 5.57 | 6.57 |

$H_1$ – mineral fertilization N, P, K + organic fertilization Veget®; $H_2$ – only mineral fertilization N, P, K

In 2011 after peas as a preceding crop the grain yield (Table 6) was significantly higher (7.71 t/ha) than in 2010 (7.21 t/ha) and 2012 (5.78 t/ha). The preceding crop had a statistically significant influence on the grain yield of winter wheat (Table 4). After peas the grain yield was statistically higher (6.81 t/ha) than after winter barley (5.59 t/ha). This agrees with the findings reported by Buraczynska et al. (2011). Grain yield, yield components, N content and N uptake in the grain of winter wheat following field pea and spring triticale/field pea mixtures were significantly higher compared with winter wheat following spring triticale. According to Montemurro (2009) crop rotation had a marked influence on the grain yield of winter wheat. Among the crop rotations, wheat after sugar beet had the highest grain yield (4.91 t/ha) and a good protein content (11.9%), while sunflower and tomato rotations had a lower grain yield (4.35 t/ha) and protein content (10.3%). Rahimizadeh et al. (2010) indicated that nitrogen use efficiency, nitrogen uptake efficiency, nitrogen utilization efficiency, nitrogen harvest index and grain protein content of wheat were significantly affected by preceding crop. In growing of winter wheat after potato the highest values of these characteristics were recorded. As shown in Table 2, the climatic conditions in years 2010–2012 were extreme in the rainfall distribution and the average daily temperature exceeded the long-term average value. This unfavourable process of climatic conditions resulted in the decrease of the grain yield. To reduce negative environmental impacts and sustain the yield levels Tuomistro et al. (2012) recommended the combination of the best practices from organic and conventional systems. An increase of grain yield can be reached by enhancing of harvesting and root residues (Merbach and Schulz 2013).

The difference between grain yield in crop rotation with 60% share of cereals with mineral fertilization + Veget® after peas as a preceding crop and the grain yield in crop rotation with 80% share of cereals with mineral fertilization after winter barley as a preceding crop was 1.98 t/ha. 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 grain yield higher than 7.0 t/ha can be reached by suitable agricultural measures.

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