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The effect of mineral fertilizers and farmyard manure on winter wheat grain yield and grain quality

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ABSTRACT

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This study evaluated how organic manures and mineral fertilizers affect winter wheat grain and straw yields and grain quality properties. The analysed period of the long-term fertilizer experiment was established in Čáslav, Czech Republic, in 1955 and covers the seasons 2011–2014. The fertilizer treatments were: control; farmyard manure (FYM); FYM + P; FYM + K; FYM + PK; FYM + N_1; FYM + N_2; FYM + N_1PK; FYM + N_2PK and FYM + N_3PK. The highest grain yields were recorded in the FYM + P and FYM + N_3PK treatments (8.9 t/ha). The highest straw yields were recorded in the FYM + N_3PK treatment (6.52 t/ha). The lowest yields were provided in the unfertilized control and FYM treatments. Qualitative parameters were evaluated in the control, FYM and FYM + N_3PK treatments between the years 2011 and 2013. The best quality of wheat grain was provided by the FYM + N_3PK treatment. Combination of the farmyard manure with NPK is the best way to achieve high grain yields with good quality and leads to sustainable food production.

Keywords: *Triticum aestivum* L.; yielding parameters; crude protein content; Zeleny's sedimentation test; gluten index

Wheat quality depends on the genetic potential of genotypes, applied technologies and agro-ecological conditions. Its technological quality greatly affects mineral nutrition, especially nitrogen nutrition, which, in interaction with other elements such as phosphorus and potassium, significantly affects wheat yield and quality. The soil-climate conditions are another factor influencing wheat quality and yields (Zecevic et al. 2010). The total concentration of nitrogen and other macronutrients in the upper soil layer can be influenced by the application of organic manures and mineral fertilizers (Hlisnikovský and Kunzová 2014a). Organic manures also positively influence the organic carbon content of the soil (Sradnick et al. 2014) and affect the amount of the microbial biomass in the soil horizon (Geisseler and Scow 2014).

Organic manures have direct and indirect effects. The direct effect consists of slow release of nutrients into the environment due to the mineralization process (Hlisnikovský and Kunzová 2014b), while indirect effect consists of a favourable influence on the soil structure (Biau et al. 2012). The combined application of organic manures and mineral fertilizers plays an important role in optimizing soil nutrient pool, increasing crop yields or increasing the efficiency of water use (Zhang et al. 2016).

Long-term experiments are valuable for monitoring of changes in soil fertility and crop yields that cannot be identified in short-term studies (Duan et al. 2014). Our study is part of a long-term experiment, which is carried out at the Čáslav experimental station. The aim of this study is to provide answers to questions: (i) how mineral fertilizers and farmyard manure influence grain and straw yield of winter wheat, and (ii) how they influence grain quality.

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Table 1. Basic description of meteorological conditions in the Čáslav crop rotation experiment (2011–2014)

Mean annual temperature (°C)					Mean annual precipitation (mm)					Cropping area	Altitude (m a.s.l.)
1956–2006	2011	2012	2013	2014	1956–2006	2011	2012	2013	2014		
8.9	9.9	9.7	9.3	11.4	556	511	640	621	618	sugar beet	263

MATERIAL AND METHODS

Site description. In 1955, the Čáslav Crop Rotation Experiment was established in the central part of the Czech Republic close to the town of Čáslav, 75 km east of Prague (49°53'29''N, 15°23'42''W). The soil is Greyic Phaeozem (WRB 2015), developed on loess, with a 40–50 cm thick humus horizon. The proportion of clay is 20.7% in the arable layer and the soil is loamy. The basic description of the experimental site is shown in Table 1 and Figure 1.

Experimental design. The long-term experiment in Čáslav has been arranged in four neighbouring fields. The area of each field is 0.4 ha (1.6 ha altogether). Each field is divided into 8 × 8 m experimental plots (48 plots in each field, 192 monitoring plots altogether). To eliminate the edge effect, only the central 5 m × 5 m area of each 8 m × 8 m experimental plot is used for the determination of yields and soil sample collection. Each field contains four independent replicates of all fertilizer treatments. The crop rotation of the experiment consists of spring barley, red clover, winter wheat, maize, spring barley, rapeseed, triticale and potatoes. A pre-crop for winter wheat was potatoes. The height of the stubble after harvest was about 8–10 cm. For the purpose of this paper 10 fertilized treatments were evaluated to analyse the effect of fertilizer treatments on grain and straw yields: unfertilized control (C); farmyard manure (FYM); FYM + P; FYM + K; FYM + PK; FYM + N_1; FYM + N_2; FYM + N_1PK; FYM + N_2PK and FYM + N_3PK. Three fertilizer treatments were evaluated to analyse the effect of fertilizer treatments on grain quality: C, FYM and FYM + N_3PK. Farmyard manure was within the frame of crop rotation applied to the potatoes at the dose 40 t/ha (approximately 200, 56 and 236 kg of N, P and K/ha, respectively). The FYM was applied, as well as mineral P and K fertilizers, in the autumn and was ploughed down immediately after application. Mineral nitrogen was applied as calcium ammonium nitrate and its dose was separated into three equivalent doses (before sowing, early spring – BBCH 30–32 (production) and late spring – BBCH 49–51 (qualitative)). The P and K fertilizers were applied as superphosphate and potassium chloride, respectively. The application rates of N, P and K (kg/ha) applied to winter wheat are given in Table 2.

Winter wheat (cv. Mulan) was sown in October 2010–2013 with a seed depth of 3–4 cm and the distance between rows 12.5 cm. The seeding rate was 190 kg/ha (400 seeds per square meter). Pesticides were used as needed and growth regulators were not used.

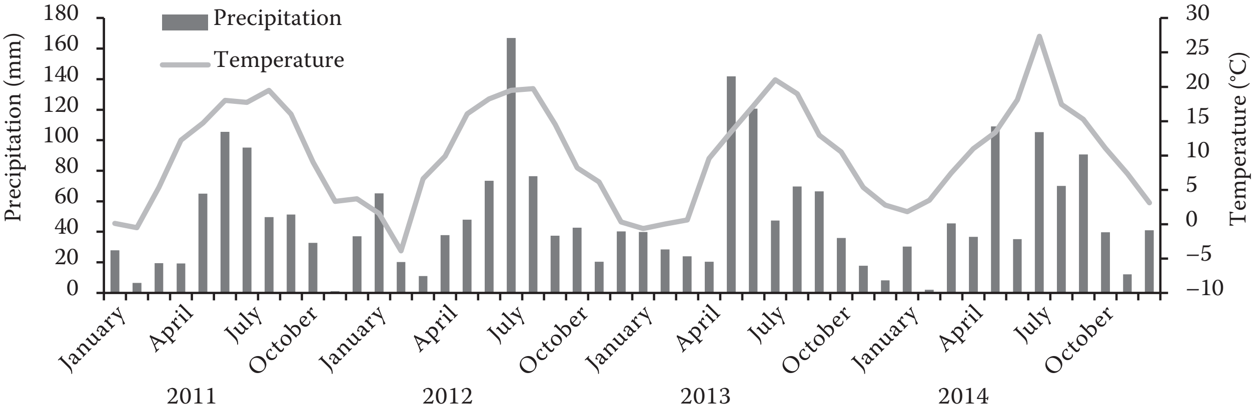

Figure 1. The mean precipitation and temperature during the years 2011–2014

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Table 2. Application rates of N, P and K (kg/ha) applied to winter wheat

Treatment	N	P	K
Control	–	–	–
FYM (farmyard manure)	–	–	–
FYM + P	–	60	–
FYM + K	–	–	60
FYM + PK	–	60	60
FYM + N_1	40	–	–
FYM + N_2	80	–	–
FYM + N_1PK	40	60	60
FYM + N_2PK	80	60	60
FYM + N_3PK	120	60	60

Analysis of grain properties. Analysis of the grain properties was performed only for grain samples from three fertilizer treatments: C; FYM and FYM + N_3PK. The subject of the analysis was thousand grain weight (TGW); crude protein content (CP); volume weight (VW); Zeleny's sedimentation test (ZST); wet gluten content (WG) and gluten index (GI). Crude protein content was analysed according to the Kjeldahl method (ČSN EN ISO 20483, 2007). To describe the baking quality of the wheat in our experiment, the Zeleny´s sedimentation test according to the standard method (ČSN ISO 5529, 2011) was performed, describing the degree of sedimentation of flour suspended in lactic acid solution during a standard time interval. The swelling of the gluten fraction of flour in a lactic acid solution affects the rate of sedimentation of flour suspension. Both, higher gluten content and better gluten quality give rise to slower sedimentation and higher Zeleny's test values (Hrušková and Faměra 2003). To discover whether the gluten of our wheat was inadequate, sufficient, average, or excellent, gluten index was assessed using Glutomatic 2200 (Perten instruments, Hägersten, Sweden) according to the standard method AACC 38-12 (1999). Gluten separated by Glutomatic (Perten) was centrifuged 1 min at 6 000 rpm to force wet gluten through a specially constructed sieve under standardized conditions. The percentage of wet gluten remaining on the sieve after centrifugation was defined as the gluten index.

Data analysis. All statistical analyses were performed using Statistica 13.3 software (www.tibco.com). The effect of fertilizer treatment over the years was analysed by factorial ANOVA and the effect of the fertilizer treatments during the year by one-way ANOVA. After obtaining significant ANOVA results, a Tukey's *HSD* (honestly significant difference) post hoc test was applied to determine significant differences among individual treatments and years.

RESULTS

Grain yield. In 2011, the highest grain yield was recorded in fertilizer treatments FYM + N_3PK (10.77 t/ha) and FYM + P (10.18 t/ha) (Table 3). On the other hand, the lowest grain yields were provided in the control treatment (6.39 t/ha), FYM (7.01 t/ha) and FYM + PK (7.03 t/ha). Application of P and K with FYM provided higher yields than FYM with N_1 and N_2 (Table 3). The year 2012 showed an overall decrease in yields, for example the mean grain yield in the control treatment was 5.27 t/ha (Table 3). The application of fertilizers (manure, manure with mineral fertilizers) this year did not have a significant impact and mean yields varied from 6.19 t/ha (FYM + K) to 6.79 t/ha (FYM + P). The overall lower yields were recorded also in the following year, 2013. As in 2011, application of FYM and FYM + PK resulted in comparable grain yields with the control treatment. All the other treatments provided significantly higher yields (Table 3) in 2013, but overall lower yields compared to 2011, and ranged from 8.46 t/ha (FYM + N_1PK) to 8.89 t/ha (FYM + N_2). Grain yields in the year 2014 were comparable with the year 2011. No significant differences were recorded between the control, FYM and FYM + PK. The highest grain yields were provided in FYM + N_2 (10.32 t/ha) and FYM + P (10.00 t/ha). Comparison of the mean grain yields from individual years shows that the highest grain yields were obtained in 2014 (9.05 t/ha), while the lowest in 2012 (6.39 t/ha). According to MANOVA, the effect of the year (F = 839.0, P < 0.001) was higher than the effect of the fertilizer treatment (F = 166.5, P < 0.001). Comparing the analysed fertilizer treatments during 2011–2014, the lowest yields were found at the control treatment. The application of FYM provided the same yields as application of FYM + PK (7.25 t/ha). The best results were found after the application of FYM + P (8.96 t/ha)

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Table 3. Grain yield (t/ha) as affected by years (2011–2014) and fertilizer treatments

Treatment	2011	2012	2013	2014	Mean treatment (2011–2014)
Control	6.39 ± 0.17^{Ac}	5.27 ± 0.04^{Db}	7.33 ± 0.13^{Ba}	6.98 ± 0.10^{Da}	6.49 ± 0.21^{F}
FYM	7.01 ± 0.18^{Aab}	6.43 ± 0.08^{ACa}	7.66 ± 0.13^{Bbc}	7.91 ± 0.22^{Ec}	7.25 ± 0.17^{D}
FYM + P	10.18 ± 0.13^{EFa}	6.79 ± 0.06^{Bb}	8.86 ± 0.08^{Ac}	10.0 ± 0.06^{ABa}	8.96 ± 0.35^{C}
FYM + K	9.98 ± 0.14^{DEa}	6.19 ± 0.04^{Cb}	8.67 ± 0.06^{Ac}	9.68 ± 0.15^{ABCa}	8.63 ± 0.39^{AB}
FYM + PK	7.03 ± 0.18^{Aab}	6.55 ± 0.04^{ABa}	7.89 ± 0.22^{BCd}	7.53 ± 0.23^{DEcd}	7.25 ± 0.15^{D}
FYM + N_1	9.07 ± 0.15^{BCa}	6.58 ± 0.06^{ABb}	8.81 ± 0.17^{Aa}	9.62 ± 0.06^{ABCc}	8.52 ± 0.30^{AE}
FYM + N_2	9.34 ± 0.06^{BCDa}	6.61 ± 0.05^{ABb}	8.89 ± 0.19^{Aa}	10.32 ± 0.11^{Bc}	8.79 ± 0.35^{ABC}
FYM + N_1PK	8.80 ± 0.15^{Bab}	6.69 ± 0.05^{ABc}	8.46 ± 0.14^{ACa}	9.12 ± 0.11^{Cc}	8.27 ± 0.25^{E}
FYM + N_2PK	9.73 ± 0.17^{CDEa}	6.21 ± 0.06^{Cb}	8.73 ± 0.24^{Ac}	9.84 ± 0.03^{ABa}	8.63 ± 0.38^{AB}
FYM + N_3PK	10.77 ± 0.03^{Fd}	6.53 ± 0.06^{ABa}	8.88 ± 0.15^{Ab}	9.50 ± 0.22^{ACc}	8.92 ± 0.40^{BC}
Mean/year	8.83 ± 0.23^{a}	6.39 ± 0.07^{b}	8.42 ± 0.10^{c}	9.05 ± 0.18^{d}	–

Means with standard errors of the mean followed by the same letter (^{A}vertically, ^{a}horizontally) were not significantly different at 0.05 probability level. FYM – farmyard manure

and FYM + N_3PK (8.92 t/ha). Mean grain yields of other treatments varied from 8.27 t/ha (FYM + N_1PK) to 8.79 t/ha (FYM + N_2).

Straw yield. In 2011, the mean straw yield varied from 4.15 t/ha (control) and FYM (4.63 t/ha) to 6.68 t/ha (FYM + N_3PK). The mean straw yield of the other treatments varied from 5.06 t/ha (FYM + PK) to 6.06 t/ha (FYM + N_2PK). The mean straw yield was 5.41 t/ha in 2011 (Table 4). In 2012, the mean straw yield varied from 3.50 t/ha (control) to 5.18 t/ha (FYM + N_3PK) (Table 4). The mean straw yield was 4.37 t/ha in 2012 (Table 4). In 2013, the mean straw yield varied from 2.81 t/ha (control) to 5.61 t/ha (FYM + N_2). The mean straw yield was 4.40 t/ha in 2013. The highest straw yields were found in 2014 and varied from 5.39 t/ha (control) to 8.78 t/ha (FYM + N_3PK). The mean straw yield was 7.03 t/ha in 2014 (the highest yields over all years). Comparing the fertilizer treatments, the lowest straw yields were obtained in control (3.96 t/ha), while the highest in the FYM + N_3PK treatment (6.52 t/ha).

Table 4. Straw yield (t/ha) as affected by years (2011–2014) and fertilizer treatments

Treatment	2011	2012	2013	2014	Mean treatment (2011–2014)
Control	4.15 ± 0.07^{Dc}	3.50 ± 0.06^{Bb}	2.81 ± 0.08^{Fa}	5.39 ± 0.15^{Cd}	3.96 ± 0.25^{D}
FYM	4.64 ± 0.08^{Cb}	3.82 ± 0.12^{BCa}	3.90 ± 0.11^{Ba}	5.50 ± 0.07^{Cc}	4.46 ± 0.18^{C}
FYM + P	5.90 ± 0.07^{Bc}	4.81 ± 0.04^{AEb}	4.04 ± 0.12^{ABa}	7.71 ± 0.16^{ABd}	5.62 ± 0.36^{AB}
FYM + K	5.32 ± 0.08^{Ab}	4.50 ± 0.07^{ADa}	4.48 ± 0.12^{Aa}	8.10 ± 0.22^{BDc}	5.60 ± 0.39^{AB}
FYM + PK	5.06 ± 0.13^{ACc}	3.89 ± 0.06^{BCa}	4.11 ± 0.08^{ABa}	5.67 ± 0.14^{Cd}	4.68 ± 0.19^{C}
FYM + N_1	5.16 ± 0.07^{Aa}	4.67 ± 0.12^{Aa}	4.48 ± 0.13^{ACa}	7.21 ± 0.27^{ABb}	5.38 ± 0.29^{A}
FYM + N_2	5.31 ± 0.09^{Aa}	4.19 ± 0.05^{CDb}	5.61 ± 0.10^{Ea}	7.28 ± 0.16^{ABc}	5.59 ± 0.29^{AB}
FYM + N_1PK	5.83 ± 0.12^{Bb}	4.68 ± 0.12^{Aa}	4.16 ± 0.09^{ABa}	7.04 ± 0.35^{Ac}	5.43 ± 0.30^{A}
FYM + N_2PK	6.06 ± 0.11^{Bc}	4.43 ± 0.12^{ADa}	4.98 ± 0.11^{CDb}	7.60 ± 0.17^{ABd}	5.77 ± 0.32^{B}
FYM + N_3PK	6.68 ± 0.12^{Eb}	5.18 ± 0.08^{Ea}	5.43 ± 0.10^{DEa}	8.78 ± 0.11^{Dc}	6.52 ± 0.37^{E}
Mean/year	5.41 ± 0.11^{b}	4.37 ± 0.08^{a}	4.40 ± 0.13^{a}	7.03 ± 0.18^{c}	–

Means with standard errors of the mean followed by the same letter (^{A}vertically, ^{a}horizontally) were not significantly different at 0.05 probability level. FYM – farmyard manure

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Grain properties

Thousand grain weight. The TGW significantly fluctuated between years and fertilizer treatments. The lowest mean TGW was recorded in 2012 (43.63 g),while the highest in 2013 (48.85 g). Comparing the fertilizer treatments, the highest TGW was found in FYM + N_3PK treatment (48.37 g), while the lowest in the control treatment (45.60 g) (Table 5).

Crude protein content. The lowest CP was recorded in 2011 (9.49%) and the highest in 2012 (12.80%). Evaluating the fertilizer treatments, the highest mean CP content was recorded in FYM + N_3PK treatment (13.21%), while the lowest in the control treatment (10.59%) (Table 5).

Volume weight. The lowest VW was recorded in 2012 (738.57 g/dm^3), while the highest in 2013 (764.27 g/dm^3). Comparing the fertilizer treatments, the highest VW was provided by FYM + N_3PK treatment (761.57 g/dm^3), while the lowest by control (741.23 g/dm^3) (Table 5).

Zeleny's sedimentation test. The ZST significantly varied between years and fertilizer treat-

Table 5. Thousand grain weight, crude protein content, volume weight, Zeleny's sedimentation test, wet gluten content and gluten index as affected by fertilizer treatments (control, FYM and FYM + N_3PK)

	Treatment	2011	2012	2013	Mean treatment
Thousand grain weight (g)	control	46.98 ± 0.34^{Aa}	42.18 ± 0.20^{Ab}	47.65 ± 0.64^{Aa}	45.60 ± 0.77^{A}
	FYM	47.60 ± 0.27^{Aa}	43.35 ± 0.41^{Bb}	48.23 ± 0.43^{Aa}	46.39 ± 0.68^{B}
	FYM + N_3PK	49.05 ± 0.37^{Bb}	45.38 ± 0.23^{Ca}	50.68 ± 0.40^{Bc}	48.37 ± 0.69^{C}
	mean/year	47.88 ± 0.31^{b}	43.63 ± 0.43^{a}	48.85 ± 0.47^{c}	–
Crude protein content (%)	control	8.46 ± 0.14^{Ab}	11.92 ± 0.16^{Aa}	11.41 ± 0.28^{Aa}	10.59 ± 0.47^{A}
	FYM	8.75 ± 0.24^{Ab}	12.24 ± 0.35^{Aa}	11.60 ± 0.30^{Aa}	10.86 ± 0.48^{A}
	FYM + N_3PK	11.27 ± 0.30^{Bb}	14.25 ± 0.20^{Ba}	14.11 ± 0.20^{Ba}	13.21 ± 0.43^{B}
	mean/year	9.49 ± 0.40^{b}	12.80 ± 0.34^{a}	12.37 ± 0.40^{a}	–
Volume weight (g/dm^3)	control	743.00 ± 1.54^{Ab}	723.10 ± 1.47^{Aa}	757.60 ± 4.20^{c}	741.23 ± 4.49^{A}
	FYM	741.80 ± 4.33^{Aa}	741.40 ± 3.24^{Ba}	763.60 ± 5.38^{b}	748.93 ± 3.88^{B}
	FYM + N_3PK	761.90 ± 0.44^{Bb}	751.20 ± 2.36^{Ca}	771.60 ± 1.39^{c}	761.57 ± 2.65^{C}
	mean/year	748.90 ± 3.11^{b}	738.57 ± 3.74^{a}	764.27 ± 2.72^{c}	–
Zeleny's sedimentation test (mL)	control	13.50 ± 0.29^{Aa}	28.88 ± 0.55^{Ac}	21.75 ± 1.31^{Ab}	21.38 ± 1.94^{A}
	FYM	16.00 ± 0.71^{Aa}	31.75 ± 2.57^{Ac}	23.50 ± 1.44^{Ab}	23.75 ± 2.14^{A}
	FYM + N_3PK	26.75 ± 1.25^{Ba}	53.63 ± 1.25^{Bc}	34.25 ± 0.85^{Bb}	38.21 ± 3.46^{B}
	mean/year	18.75 ± 1.79^{a}	38.08 ± 3.45^{c}	26.50 ± 1.79^{b}	–
Wet gluten content (%)	control	12.55 ± –^{Aa}	23.59 ± 0.36^{Ab}	18.59 ± 1.97^{Aab}	20.14 ± 1.50^{A}
	FYM	14.45 ± –^{Aa}	25.88 ± 1.02^{Ab}	21.01 ± 1.70^{Aab}	22.44 ± 1.52^{A}
	FYM + N_3PK	22.78 ± 0.64^{Ba}	36.35 ± 0.41^{Bc}	29.53 ± 0.95^{Bb}	30.17 ± 1.74^{B}
	mean/year	19.07 ± 2.32^{a}	28.60 ± 1.71^{c}	23.04 ± 1.64^{b}	–
Gluten index	control	99.59 ± –^{a}	85.48 ± 1.30^{Cb}	96.76 ± 2.26^{Ba}	92.06 ± 2.36^{B}
	FYM	99.65 ± –	69.47 ± 5.54^{B}	88.65 ± 9.90^{AB}	81.35 ± 6.08^{B}
	FYM + N_3PK	93.73 ± 1.51^{b}	50.51 ± 2.44^{Aa}	65.01 ± 6.17^{Aa}	67.57 ± 5.87^{A}
	mean/year	96.09 ± 1.66^{a}	68.48 ± 4.70^{b}	83.47 ± 5.42^{a}	–

Means with standard errors of the mean followed by the same letter (^{A}vertically, ^{a}horizontally) were not significantly different at 0.05 probability level. FYM – farmyard manure

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ments. The lowest mean ZST was recorded in 2011 (18.75 mL), while the highest in 2012 (38.08 mL). Evaluating the fertilizer treatments, the lowest value was recorded in the control treatment (21.38 mL), while the highest in FYM + N_3PK treatment (38.21 mL) (Table 5).

Wet gluten content. The lowest mean WG was recorded in 2011 (19.07%), the highest then in 2012 (28.60%). Comparing the fertilizer treatments, the mean WG content varied from 20.14% (control) to 30.17% (FYM + N_3PK) (Table 5).

Gluten index. The lowest mean GI was recorded in 2012 (68.48), the highest in 2011 (96.09). Comparing the fertilizer treatments, the highest mean GI was obtained in the control treatment (92.06) and the lowest in FYM + N_3PK treatment (87.57) (Table 5).

DISCUSSION

The aim of our work was to determine how the application of manure and manure in combination with mineral fertilizer in soils of the test areas affects yields of grain, including its qualitative parameters, and straw of winter wheat. The smallest effect on the yield of winter wheat grain was obtained at the application of manure. A similar effect of the application of manure on the yield of grain was determined for example by Zhang et al. (2016). A very low effect of manure in years 2011–2012, is described for example by Zhang et al. (2017) and they state that the lower yield could be caused by the permanent loss of mineralised nitrogen by leaching and processes connected with evaporation which reduced the effect of the nitrogen use. The application of manure in combination with potassium and phosphorus had a similar effect on yields. In the present study, there was also a 12% increase of yields compared to the control. Hejcman et al. (2012) determined a low effect, no effect as the case may be, of the application of manure in combination with P and K in their work. Production was not restricted by the amount of potassium in the soil, which shows that the concentration of its available forms for the plant was convenient or even high for the production of winter wheat (Hermann and Tóth 2011). The combined use of organic manures and mineral fertilizers leads to an increase of the nitrogen concentration, better use of phosphorus and potassium as a consequence of the improved soil properties, better absorption of water and nutrients from the soil and applied fertilizers (Brar et al. 2015). The simultaneous use of manure and mineral fertilizers increasing the intake of nutrients by plants is also stated by Sheoran et al. (2017). Liang et al. (2013) found that the combined application of fertilizers significantly improved the immobilisation of nitrogen by fertilizer in the initial stages of wheat cultivation, when the crop demand for nutrition with nitrogen is small. In the period of the plant growth, nitrogen is released from the reservoir consisting of microorganisms. This mechanism shows that the combined application of fertilizers can increase the synchronisation between the supply of nitrogen and its demand by a specific crop, which helps reduce the loss of nitrogen in agriculture (Zhang et al. 2016). The speed of fertilizer mineralisation also depends on weather conditions as manure mineralises more slowly during a dry period than in a period with sufficient precipitation (Hlisnikovský et al. 2016).

Our results show that the combined application of organic and mineral fertilizers brings higher yields in winter wheat. The work of other authors (e.g. Duan et al. 2014, Sheoran et al. 2017) also shows that there is an improvement in the quality of seed and therefore this increases the nutrients added through combined fertilization than when fertilizers are used on their own. All these facts reach the conclusion that there is a need to focus more on using a combination of organic manures and mineral fertilizers. This may result in sustainable production and agriculture being more environment-friendly.

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