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Effect of Mineral and Organic Fertilizers on Yield and Technological Parameters of Winter Wheat (*Triticum aestivum* L.) on Illimerized Luvisol

Lukáš Hlisnikovský, Eva Kunzová

Department of Nutrition Management, Crop Research Institute
Drnovská 507, CZ-161 01 Prague 6, Ruzyně, Czech Republic

Abstract. As livestock production has decreased dramatically in the Czech Republic in the last 25 years, the amount of organic fertilizers applied to farmland has also declined. In the interest of the effect of organic materials applied to arable land, we took advantage of a long-term fertilizer experiment in Prague-Ruzyně to evaluate the influence of mineral fertilizer and mineral fertilizer combined with organic fertilizers on grain and straw yield and quality parameters of our most important arable crop, winter wheat (*Triticum aestivum* L.). We evaluated nine fertilizer treatments: Control, Np, PKNp, NPK, NPK+farmyard manure (NPK+FYM), NPK+cattle slurry (NPK+CS), NPK+cattle slurry+straw (NPK+CS+straw), NPK+pig slurry (NPK+PS) and NPK+pig slurry+straw (NPK+PS+straw) in two successive seasons (2010 and 2011).

In 2010, the mean grain yields were 4.8, 6.47, 8.77, 9.19, 9.26 and 9.38 t ha^{-1} in Control, Np, NPK, NPK+FYM, NPK+CS and NPK+CS+straw treatments, respectively. One year later, the mean grain yields were 5.29, 5.35, 8.06, 8.84, 9.01 and 9.52 t ha^{-1} in Control, PKNp, NPK, NPK+FYM, NPK+PS+straw and NPK+PS treatments, respectively. The straw yield, seed bulk density, crude protein content, starch content and Zeleny sedimentation test value were also significantly influenced by fertilizer treatments. Comparing Control, FYM and FYM+NPK treatments in 2010 and 2011, significant differences were recorded in straw yield, seed bulk density, crude protein content, starch content and Zeleny sedimentation test value.

We concluded that the grain and straw yield, together with grain technological parameters can be significantly influenced by the application of mineral and organic fertilizers and can significantly differ between seasons. A combination of mineral and organic fertilizers can even directly increase yield and quality parameters in comparison to mineral fertilizers applied alone.

key words: *Triticum aestivum*, farmyard manure, cattle slurry, pig slurry, crude protein content, starch content, Zeleny sedimentation test

Corresponding author:
Lukáš Hlisnikovský
tel: +420 773 636 546
e-mail: l.hlisnik@vurv.cz

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INTRODUCTION

Approximately 3,518,000 tonnes of winter wheat were harvested from 815,000 ha in 2012, covering almost 33% of the Czech Republic cropland area (Czech Statistical Office, 2014). In comparison with cereals and other agricultural crops, winter wheat represents the most important agricultural crop in Czech agriculture.

Winter wheat grain yield and quality are influenced by fertilization treatment, environmental factors and by the genetic predispositions of a particular variety. It is commonly known that fertilization, especially nitrogen fertilization, has a fundamental position in the attainment of high yields and high quality grain. Nitrogen positively influences the leaf area and its chlorophyll concentration, thereby inducing crude protein content and the rheological properties of dough (Blandino and Rezneri, 2009). Nitrogen positively influences root biomass formation and creates optimal conditions for successful growth (Rieger *et al*., 2008) and for high protein content (Kindred *et al*., 2008). On the other hand, nitrogen negatively affects the grain's starch content as there is a strong negative relationship between crude protein and starch content (Kindred *et al*., 2008). Application of organic fertilizers, such as farmyard manure, positively influences grain and straw yield (Coventry *et al*., 2011). Organic fertilizers have a two-fold effect. The indirect effect consists of the beneficial effect of soil parameters, such as Nmin, earthworm abundance (Biau *et al*., 2012) and soil organic matter (Yu *et al*., 2012). The direct effect consists of the slow provision of nutrients. Pratt *et al*. (1973) published that 35, 10 and 5% of the total manure nitrogen was available to crops during the first, second and third year respectively. On the other hand, a combination of mineral and organic fertilizers can cause environmental damage, as many farmers do not consider organic fertilizers, pig slurry specifically, as fertilizer, but as waste products and so they do not reduce the total amount of mineral nutrients (Berenguer *et al*., 2008). Also, organic fertilizers are constitutionally inhomogeneous and it is not recommended to depend just on table values. Rational use of organic and mineral fertilizers, based on the knowledge of their chemical composition, can lead to the same results as using mineral forms alone, thus reducing financial costs and not endangering the environment (Berenguer *et al*., 2008). Nowadays, the application of organic fertilizers is insufficient in the Czech Republic. The number of cattle has decreased from 3.48 million in 1989 to 1.35 million in 2013 and the number of pigs has decreased from 4.7 million in 1989 to 1.6 million in 2013. Together with the decreasing number of cattle and pigs, the amount of organic fertilizers is decreasing. In 2009, the average production of cattle slurry and farmyard manure was approximately 3.3 and 9.1 million Mg respectively. Production of pig slurry and of pig farmyard manure was approximately 3 and 1.2 million Mg respectively (Klír and Vegricht, 2009).

The most important quality trait of winter wheat is protein content. Many works have described and confirmed the significant effect of weather on the grain's protein content. According to López-Bellido *et al*. (1998), the protein content is inversely proportional to rainfall during the growing season. While dry seasons lead to the production of grain with a high content of proteins, increase vitreousness and decrease thousand kernel weight and ash content, during abundant rainfall seasons lower protein content can be expected (Johnson and Mattern, 1987; Rao *et al*., 1993; Rharrabti *et al*., 2003; Flagella *et al*., 2010; Gürsoy *et al*., 2010). The critical time in the final formation of grain quality is the grain filling period. The results of Graybosh *et al*. (1995) show no relationship between crude protein content and environmental conditions, other than with the duration of grain filling. Higher temperatures during the grain filling period significantly slow the conversion of sucrose to starch, but have no relevant effect on protein synthesis (Brooks *et al*., 1982; Singh *et al*., 2010).

The aim of this study was to investigate the reaction of winter wheat on the long-term application of different fertilizer treatments, including mineral fertilizers and combinations of mineral and organic fertilizers (cattle slurry, pig slurry, straw) in two successive seasons (2010 and 2011).

MATERIALS AND METHODS

Within the framework of long-term crop rotation experiments in Prague-Ruzyně, established in 1954, the analyses of grain yield (GIY), straw yield (STR) and selected grain quality parameters such as seed bulk density (DE), crude protein content (CP), starch content (STA) and Zeleny sedimentation test value (ZST) of winter wheat (*Triticum aestivum* L., var. MULAN) in 2010 and 2011 were performed.

Site description

The Ruzyně Fertilizer Experiment (RFE) was established on a permanent arable field in 1954, on the western edge of Prague. At the study site, the mean annual temperature is 8.2°C (ranging from 6.4 to 9.7°C) and the mean annual precipitation is 422 mm (ranging from 255 to 701 mm; Prague-Ruzyně Meteorological Station, 1955–2007). According to the Czech taxonomic soil classification system the soil type was classified as Illimerized Luvisol (syn. illimerized grey-brown soil). The parent material is loess mixed with highly weathered chalk. The ground water level is 20 m below the field surface. The upper 30 cm (arable layer) contains 27% clay, increasing to 40% in the subsoil (soil layer 30–40 cm) and 49% at 40–50 cm depth. The average temperature was 7.7°C and 7.3°C in 2010 and 2011 respectively. The total amount of precipitation was 541.4 mm and 504.6 mm in 2010 and 2011 respectively.

Experimental design

A split plot design with four replications was used in the experiment. Winter wheat was cultivated on experimental strip number 2 in 2010 and number 3 in 2011. Each experimental strip consists of 96 plots, where a total of 24 variants of fertilizers in four replications are running (24 x 4 = 96). The size of the experimental plot is 12 x 12 m. To eliminate the edge effect, only the central 5 x 5 m area is used for sample collection. In this paper, only nine fertilizer treatments were evaluated: Control (non-fertilized from 1954), Np (20 kg N ha^{-1} applied to straw, when the preceding crop was cereal), NPK, NPK+farmyard manure (NPK+FYM), NPK+cattle slurry (NPK+CS), NPK+cattle slurry+straw (NPK+CS+straw), PK+Np, NPK+pig slurry (NPK+PS) and NPK+pig slurry+straw (NPK+PS+straw). Specific doses of applied fertilizers and results of soil analysis are given in Tables 1 and 2. The nitrogen was applied as ammonium nitrate with lime, 27% N, phosphorus as triple superphosphate, 19.4% P and potassium as potassium chloride, 49.8% K. Nitrogen was applied in spring, phosphorus and potassium were applied in the autumn before sowing. All organic fertilizers were applied to the preceding root crop. The straw was ploughed back into the land right after harvesting of the previous cereal.

In each particular year, six different fertilizer treatments were evaluated. To evaluate the effect of the year, Control, NPK and NPK+FYM treatments were compared and statistically analyzed.

The crop rotation in this experiment consists of *Triticum aestivum*, *Beta vulgaris*, *Hordeum vulgare*, *Medicago sativa*, *Medicago sativa*, *Triticum aestivum*, *Beta vulgaris*, *Hordeum vulgare*, *Solanum tuberosum* (45% cereals, 33% root crops and 22% forage crops). In this experiment winter wheat followed *Solanum tuberosum* in the crop rotation.

Grain analysis

Grain analysis of winter wheat included assessment of grain yield (GIY), straw yield (STR), both at 86% of dry matter, seed bulk density (DE), crude protein content (CP)

Table 1. Fertilizer treatments, rates and soil chemical properties of the strip number 2 (2010). Assessment of the P, K and Mg was made according to Budňáková *et al.* (2004).

Treatment	N, P, K [kg ha^{-1}]	Organic fertilizer [t ha^{-1}]	pH	P [mg kg^{-1}]	P assessment	K [mg kg^{-1}]	K assessment	Mg [mg kg^{-1}]	Mg assessment
Control	0, 0, 0	0	6.0	23	low	132	suitable	160	suitable
Np	40, 0, 0	0	6.0	61	suitable	192	good	137	suitable
NPK	95, 60, 120	0	5.9	70	suitable	196	good	150	suitable
NPK+FYM	95, 60, 120	15	5.8	103	good	288	good	185	good
NPK+CS	95, 60, 120	32	6.4	75	suitable	225	good	146	suitable
NPK+CS+straw	95, 60, 120	32	6.2	86	good	212	good	159	suitable

Table 2. Fertilizer treatments, rates and soil chemical properties of the strip number 3 (2011). Assessment of the P, K and Mg was made according to Budňáková *et al.* (2004).

Treatment	N, P, K [kg ha^{-1}]	Organic fertilizer [t ha^{-1}]	pH	P [mg kg^{-1}]	P assessment	K [mg kg^{-1}]	K assessment	Mg [mg kg^{-1}]	Mg assessment
Control	0, 0, 0		5.9	17	low	142	suitable	182	good
PK+Np	40, 60, 120		5.8	30	low	121	suitable	133	suitable
NPK	95, 60, 120		5.6	67	suitable	183	good	140	suitable
NPK+FYM	95, 60, 120	15	5.9	96	good	230	good	172	good
NPK+PS	95, 60, 120	49	5.6	130	high	227	good	153	suitable
NPK+PS+straw	95, 60, 120	49	5.7	106	good	216	good	163	good

according to the Kjeldahl method (ČSN EN ISO 20483), starch content (STA) according to ČSN EN ISO 10520 and the Zeleny sedimentation test (ZST) according to ČSN ISO 5529.

Statistical analysis

All statistical analyses were performed using STATISTICA 10.0 software (StatSoft, 2011). The effect of different fertilizer treatments on particular strips in 2010 and 2011 and of the year was analyzed by one-way ANOVA. The effect of fertilizer treatment*year interaction was analyzed by multivariate analysis of variance (MANOVA). After obtaining significant results, a Tukey's HSD post hoc test was applied to determine significant differences among individual treatments and years.

RESULTS

Weather conditions

The average temperature and precipitation of the 2010 season was 7.7°C and 541.4 mm. The 2011 season was slightly colder (7.4°C) and poorer in precipitation (504.8 mm).

Grain yield

In 2010, GIY was significantly influenced by fertilizer treatment (d. f. = 5, F = 107.3, $p < 0.001$). The lowest GIY was provided by Control treatment (4.8 t ha^{-1}), while the highest by NPK+CS+straw treatment (9.38 t ha^{-1}). The GIY increased with an increasing dose of nitrogen (Control–Np–NPK). Application of organic fertilizers slightly increased GIY, if compared to NPK, but the effect was not statistically significant. The yield of Np treatment was significantly higher in comparison to Control, but also significantly lower in comparison to NPK and NPK accompanied with organic fertilizers. In 2011, GIY was also significantly influenced by fertilizer treatment (d. f. = 5, F = 70.77, $p < 0.001$). GIY varied from 5.29 t ha^{-1} (Control) to 9.52 t ha^{-1} (NPK+PS). Application of mineral fertilizers and mineral fertilizers accompanied with organic fertilizers significantly increased GIY when compared to Control or PK+Np (Table 3).

Comparing the years, no statistically significant effect of the year was revealed (d. f. = 1, F = 1.5, p = 0.242). The average GIY was 7.59 t ha^{-1} and 7.4 t ha^{-1} in 2010 and 2011 respectively (Table 4).

Straw yield

In 2010, STR was significantly affected by fertilizer treatment (d. f. = 5, F = 65.71, $p < 0.001$). STR ranged from 1.68 t ha^{-1} (Control) to 5.8 t ha^{-1} (NPK+FYM). Application of mineral fertilizer and mineral fertilizers accompanied with organic fertilizers increased STR significantly, when compared to Control or Np. The straw yield of Np treatment was significantly higher in comparison to Control, but significantly lower in comparison to NPK and NPK accompanied with organic fertilizers. Also in 2011 the STR

Table 3. The effect of fertilizer treatments on grain yield (GIY), straw yield (STR), seed bulk density (DE), crude protein content (CP), starch content (STA) and the value of Zeleny sedimentation test (ZST) of winter wheat on strip 2 (2010) and strip 3 (2011).

Treatment	GIY (t ha^{-1})	STR (t ha^{-1})	DE (g dm^{-3})	CP (%)	STA (%)	ZST (ml)
Strip 2 (2010)						
Control	$4.80±0.23^{A}$	$1.68±0.03^{A}$	$707.35±7.26^{A}$	$10.65±0.20^{A}$	$66.22±0.18^{BC}$	$27.50±1.04^{A}$
Np	$6.47±0.07^{B}$	$3.03±0.24^{B}$	$729.93±5.87^{AB}$	$10.28±0.18^{A}$	$66.62±0.31^{C}$	$24.75±0.75^{A}$
NPK	$8.77±0.16^{C}$	$4.89±0.21^{C}$	$747.88±7.06^{B}$	$12.85±0.43^{B}$	$65.69±0.20^{AB}$	$38.50±3.23^{B}$
NPK+FYM	$9.19±0.17^{C}$	$5.80±0.21^{C}$	$751.43±4.71^{B}$	$13.51±0.24^{B}$	$64.84±0.17^{A}$	$39.50±1.94^{B}$
NPK+CS	$9.26±0.24^{C}$	$5.57±0.29^{C}$	$746.63±6.54^{B}$	$13.50±0.14^{B}$	$64.82±0.16^{A}$	$42.50±1.55^{B}$
NPK+CS+straw	$9.38±0.18^{C}$	$5.34±0.16^{C}$	$751.86±4.50^{B}$	$13.86±0.17^{B}$	$64.85±0.13^{A}$	$42.75±2.10^{B}$
Strip 3 (2011)						
Control	$5.29±0.09^{A}$	$1.63±0.16^{A}$	$757.63±1.90^{A}$	$8.80±0.20^{A}$	$67.12±0.12^{B}$	$17.00±0.41^{A}$
PK+Np	$5.35±0.18^{A}$	$2.04±0.18^{A}$	$761.23±1.75^{A}$	$8.84±0.25^{A}$	$66.84±0.12^{AB}$	$17.25±0.48^{A}$
NPK	$8.06±0.24^{B}$	$3.26±0.10^{B}$	$778.90±2.86^{B}$	$10.69±0.50^{B}$	$66.48±0.32^{AB}$	$26.25±1.65^{B}$
NPK+FYM	$8.84±0.24^{BC}$	$3.89±0.10^{C}$	$786.53±3.00^{BC}$	$11.92±0.27^{BC}$	$65.65±0.49^{A}$	$31.50±2.10^{BC}$
NPK+PS	$9.52±0.16^{C}$	$3.58±0.13^{BC}$	$791.08±4.29^{BC}$	$12.07±0.46^{BC}$	$65.53±0.48^{A}$	$32.75±2.10^{BC}$
NPK+PS+straw	$9.01±0.35^{BC}$	$3.67±0.08^{BC}$	$792.55±2.27^{C}$	$12.43±0.38^{C}$	$65.64±0.15^{A}$	$34.50±1.04^{C}$

Means with standard errors of the mean (SE) followed by the same letter were not significantly different at 0.05 probability level.

Table 4. The grain yield (GIY), straw yield (STR), seed bulk density (DE), crude protein content (CP), starch content (STA) and the value of Zeleny sedimentation test (ZST) as influenced by year. The results are the average values from the three identical fertilizer treatments (Control, NPK, NPK+FYM) applied in 2010 and 2011 in both strips.

Year	GIY (t ha^{-1})	STR (t ha^{-1})	DE (g dm^{-3})	CP (%)	STA (%)	ZST (ml)
2010	$7.59±0.61^{A}$	$4.12±0.54^{B}$	$735.55±6.91^{A}$	$12.34±0.40^{B}$	$65.58±0.20^{A}$	$35.17±2.02^{B}$
2011	$7.40±0.47^{A}$	$2.93±0.29^{A}$	$774.35±3.94^{B}$	$10.47±0.43^{A}$	$66.41±0.26^{B}$	$34.92±1.98^{A}$

Means with standard errors of the mean (SE) followed by the same letter were not significantly different at 0.05 probability level.

was significantly influenced by fertilizer treatment (d. f. = 5, F = 51.72, $p < 0.001$). The STR varied from 1.63 t ha^{-1} (Control) to 3.89 t ha^{-1} (NPK+FYM). Application of mineral and organic forms of fertilizers significantly increased STR, when compared to Control or PK+Np treatments (Table 3).

A statistically significant effect of the year on straw yield was revealed, when comparing 2010 and 2011 (d. f. = 1, F = 95, $p < 0.001$). The average STR was 4.12 and 2.93 t ha^{-1} in 2010 and 2011 respectively (Table 4).

Seed bulk density

In 2010, statistically significant differences were revealed between fertilizer treatments (d. f. = 5, F = 8.32, $p < 0.001$). The DE ranged from 707.35 g dm^{-3} (Control) to 751.86 g dm^{-3} (NPK+CS+straw). Addition of mineral and organic fertilizers significantly increased DE, when compared to Control. No differences were revealed between NPK and NPK enriched with organic compounds. The effect of fertilizer treatments was also significant in 2011 (d. f. = 5, F = 29.15, $p < 0.001$). The DE varied from 757.63 g dm^{-3} (Control) to 792.55 g dm^{-3} (NPK+PS+straw). Significant differences were revealed between Control and NPK and between NPK and NPK+PS+straw (Table 3).

The effect of the year was statistically significant (d. f. = 1, F = 93.07, $p < 0.001$). The average DE was 735.55 g dm^{-3} and 774.35 g dm^{-3} in 2010 and 2011 respectively (Table 4).

Crude protein content

Crude protein content was significantly influenced by fertilizer treatment (d. f. = 5, F = 40.43, $p < 0.001$) in 2010. The lowest CP was recorded in Np treatment (10.28%), while the highest in NPK+CS+straw (13.86%). Significant differences were revealed between treatments without direct fertilizer input (Control and Np) and with fertilizer input, but no differences were recorded between mineral fertilizer (NPK) and mineral fertilizers accompanied with organic compounds. In 2011 the CP was also significantly influenced by fertilizer treatment (d. f. = 5, F = 20.59, $p < 0.001$). The CP ranged from 8.8% (Control) to 12.43% (NPK+PS+straw). Addition of pig slurry and straw to the mineral form of fertilizer increased CP significantly, when compared to the mineral form without organic compound (Table 3).

The CP varied significantly between the years (d. f. = 1, F = 48.3, $p < 0.001$), revealing the influence of weather conditions. The average CP was 12.34% and 10.47% in 2010 and 2011 respectively (Table 4).

Starch content

The STA varied significantly between fertilizer treatments in 2010 (d. f. = 5, F = 15.82, $p < 0.001$), ranging from 64.82% (NPK+CS) to 66.62% (Np). A significantly lower content of starch was provided by treatments accompanied with organic compounds, when compared to the Control and Np treatments. In 2011 the STA was also significantly influenced by fertilizer treatments (d. f. = 5, F = 4.59, $p < 0.01$). The STA varied from 65.53% (NPK+PS+straw) to 67.12% (Control). Significant differences were revealed between Control and mineral fertilizers enriched with organic compounds (Table 3).

Comparing the years, STA varied significantly between 2010 and 2011 (d. f. = 1, F = 13.63, $p < 0.01$). The average STA was 65.58% and 66.41% in 2010 and 2011 respectively (Table 4).

Zeleny sedimentation test

The value of the ZST was significantly influenced by treatments in 2010 (d. f. = 5, F = 16.18, $p < 0.001$), ranging from 24.75 ml (Np) to 42.75 ml (NPK+CS+straw). The ZST value significantly increased when mineral fertilizer was added, but no differences were revealed between mineral fertilizer and mineral fertilizer accompanied with organic compounds. In 2011, the ZST varied significantly between fertilizer treatments (d. f. = 5, F = 28.01, $p < 0.001$). The lowest ZST was provided by Control treatment (17 ml), the highest by NPK+PS+straw (34.5 ml) (Table 3).

According to MANOVA results, the ZST value varied significantly between 2010 and 2011 (d. f. = 1, F = 41.91, $p < 0.001$). The average ZST value was 35.17 ml and 34.92 ml in 2010 and 2011 respectively (Table 4).

DISCUSSION

The main message of this paper is that the application of mineral and mineral fertilizers combined with organic fertilizers provided significantly higher GIY and STR, DE, CP and ZST value and decreased STA. Also, grain quality parameters were significantly influenced by the weather conditions of a particular season.

Application of organic fertilizers can implicitly improve yields and quality traits by increasing the organic matter, alkaline nitrogen, available phosphorus and potassium and reduce soil bulk density and improve field moisture capacity (Jiang *et al*., 2006; Zhao and Zhou, 2011) and accelerate the accumulation of soil organic carbon and nitrogen content (Ndayegamiye and Côté, 1988; Zhengchao *et al*., 2013). In our case, the application of NPK with cattle slurry and straw resulted in the highest GIY (9.38 t ha^{-1}) in 2010 and the application of NPK combined with pig slurry resulted in the highest GIY (9.52 t ha^{-1}) in 2011. These findings are consistent with those from Jiang *et al*. (2006), who recorded the highest yields with organic fertilizers combined with NPK and almost 1 t ha^{-1} higher yields when compared to NPK without organic compounds. The positive response of winter wheat on applied organic fertilizers was also published by Barzegar *et al*. (2002), who experimented with wheat straw, composted sugarcane bagasse residues and with farmyard manure and are also in agreement with the findings of Ailincăi *et al*. (2007), who obtained higher grain yields with NPK incorporated with farmyard manure in comparison with NPK alone.

Similarly, STR responded positively to inorganic and organic fertilizer application. The STR of NPK treatment was 191% higher and of NPK+FYM was 245% higher in 2010, when compared to Control treatment. In 2011, application of NPK increased STR by 100% and the combination of NPK with farmyard manure by as much as 138%.

To fulfil the Czech national standard A grain quality class requirements, the minimal seed bulk density of grain must be 780 g dm^{-3}. The DE is an important index of flour extraction during mill processing and higher values mean higher quality grain. In our experiment the A class minimal weight was not achieved by any treatment in 2010. Even the application of high doses of mineral fertilizers, accompanied with organic materials, provided weight ranging from 746.63 to 751.86 g dm^{-3}. One year later, application of NPK+FYM, NPK+PS and NPK+PS+straw provided sufficient DE to meet the A and even E class requirements, as all three treatments achieved values exceeding 780 g dm^{-3}.

According to Barneix (2007), the addition of N fertilizer is the most frequent practice used to influence the wheat protein content. In our experiment the addition of NPK and NPK accompanied with organic compound resulted in substantially higher CP content in comparison to Control treatment. CP was significantly higher in the warmer year of 2010 than in 2011. According to the results of Kramer (1979), Johnson and Mattern (1987) and López-Bellido *et al*. (1998), the correlation between CP and GIY can be positive, negative or not at all, depending on soil fertility. In our case, the correlation between CP and GIY was strong and positive in 2010 ($r = 0.93$, $p <0.01$) and also in 2011 ($r = 0.98$, $p < 0.01$).

It is a very common situation that with increasing yields the grain CP content decreases. The GIY is mainly a function of starch accumulation. Any increase in starch accumulation dilutes the CP content, if it is not accompanied with an equivalent increase in nitrogen accumulation (Barneix, 2007). In our case, a strong negative relationship between CP and STA in 2010 ($r = -0.96$, $p < 0.01$) and in 2011 ($r = -0.97$, $p < 0.01$) was recorded, so as the GIY and CP increased with higher doses of nutrients, the STA content decreased. These results show the very good ability of organic fertilizers to provide good soil conditions and sufficient amount of nutrients during the growing period.

The ZST is mainly influenced by genetic factors (Branlard *et al*. 2001), but weather also played a significant role in our experiment, as the average ZST values were significantly different between 2010 and 2011. The effect of the weather conditions was even higher than the effect of fertilizer treatment, as the weather conditions influenced the ZST by 62% and the fertilizer treatment by 38%. The results of the ZST are equal to CP as the ZST is a function of CP and the relationship between those two parameters was very strong and positive ($r = 0.99$, $p < 0.01$) in both years. The highest values were recorded in NPK+CS+straw in 2010 and NPK+PS+straw in 2011, while the lowest in Np (2010) and Control (2011) treatments. The statistically significant effect of fertilizer treatment on the ZST has also been published by Babulicová (2008). According to the Czech national standard, none of the treatments fulfilled the requirements of E quality class (Table 5).

Table 5. Grain quality classes and requirements for food wheat grain according to the Czech national standard.

Attribute	Elite class (E)	Quality class (A)	Bread class (B)
Seed bulk density	790	780	760
Crude protein content	12.6	11.8	11.0
Zeleny sedimentation test	49	35	21

CONCLUSIONS

1. Application of mineral and organic fertilizers provided statistically higher GIY, STR, DE, CP and ZST and lower STA, when compared to the Control and Np treatments.
2. Addition of organic fertilizers to mineral form resulted in slightly higher GIY, STR, DE, CP and ZST value and lower STA, when compared to mineral form without any organic inputs. These results were not statistically significant in 2010. Though, as the weather conditions changed one year later (lower annual temperature and precipitation), differences between mineral and mineral form accompanied with organic fertilizers increased significantly in particular cases.
3. The effect of mineral and organic fertilizer application is strongly influenced by the particular conditions of weather during the season. In one year with less suitable conditions, even high doses of mineral and organic fertilizers did not provide yields with required quality parameters.

REFERENCES

Ailincăi C., Ailincăi D., Zbant M., Mercuş A., Ţopa D., Cara M., 2007. The effect of different fertilization systems on wheat yield, erosion and fertility of eroded soils from the Moldavian Plateau. Cercetări Agronomice în Moldova, Anul XXXX, Vol. 4 (132).

Babulicová M., 2008. Influence of fertilization on winter wheat in crop rotations and in long-term monoculture. Plant Soil Environ., 54: 190-196.

Barneix A., 2007. Physiology and biochemistry of source-regulated protein accumulation in the wheat grain. J. Plant Physiol., 164: 581-590.

Barzegar A.R., Yousefi A., Daryashenas A., 2002. The effect of addition of different amounts and types of organic materials on soil physical properties and yield of wheat. Plant Soil, 247: 295-301.

Berenguer P., Santiveri F., Boixadera J., Lloveras J., 2008. Fertilisation of irrigated maize with pig slurry combined with mineral nitrogen. Europ. J. Agron., 28: 635-645.

Biau A., Santiveri F., Mijangos I., Lloveras J., 2012. The impact of organic and mineral fertilizers on soil quality parameters and the productivity of irrigated maize crops in semiarid regions. Europ. J. Soil Biol., 53: 56-61.

Blandino M., Reyneri A., 2009. Effect of fungicide and foliar fertilizer application to winter wheat at anthesis on flag leaf senescence, grain yield, flour bread-making quality and DON contamination. Europ. J. Agron., 30: 275-282.

Branlard G., Dardevet M., Saccomano R., Lagoutte F., Gourdon J., 2001. Genetic diversity of wheat storage proteins and bread wheat quality. Euphytica, 119: 59-67.

Brooks A., Jenner C. F., Aspinall D., 1982. Effect of water deficit on endosperm starch granules and on grain physiology of wheat and barley. In: Garrido-Lestache E., López-Bellido R.J., López-Bellido L., 2005. Durum wheat quality under Mediterranean conditions as affected by N rate, timing and splitting, N form and S fertilization. Europ. J. Agron., 23: 265-278.

Budňáková M., Čermák P., Hauerland M., Klír J., 2004. Zákon o hnojivech a navazující vyhlášky. ÚZPI, Prague.

Coventry D.R., Gupra R.K., Yadav A. Poswal R.S., Chhokar R.S., Sharma R.K., Yadav V.K., Gill S.C., Kumar A., Mehta A., Kleemann S.G.L., Bonamano A., Cummins J.A., 2011. Wheat quality and productivity as affected by varieties and sowing time in Haryana, India. Field Crop Res., 123: 214-225.

Czech Statistical Office (Prague). Sowing areas of agricultural crops – Czech Republic. 11.07.2014 [cit. 14.05.2014]. Available from: http://www.czso.cz/eng/redakce.nsf/i/zem_ts

Flagella Z., Giuliani M.M., Giuzio L., Volpi Ch., Masci S., 2010. Influence of water deficit on durum wheat storage protein composition and technological quality. Europ. J. Agron., 33: 197-207.

Graybosch R.A., Peterson C.J., Baenziger P.S., Shelton D.R., 1995. Environmental modification of hard red winter wheat flour protein composition. Publications from USDA-ARS/UNL Faculty, Paper 917.

Gürsoy S., Sessiz A., Malhi S.S., 2010. Short-term effects of tillage and residue management following cotton on grain yield and quality of wheat. Field Crop Res., 119: 260-268.

Jiang D., Hengsdijk H., Dai T.B., de Boer W., Jing Q., Cao W.X., 2006. Long-term effects of manure and inorganic fertilizers on yield and soil fertility for a winter wheat-maize system in Jiangsu, China. Pedosphere, 16: 25-32.

Johnson V.A., Mattern P.J., 1987. Wheat, rye, and triticale. In: López-Bellido L., Fuentes M., Castillo J.E., López-Garrido F.J. 1998. Effects of tillage, crop rotation and nitrogen fertilization on wheat-grain quality grown under rainfed Mediterranean conditions. Field Crop Res., 57: 265-276.

Kindred D.R., Verhoeven T.M.O., Weightman R.M., Swanston J.S., Agu. R.C., Brosnan J.M., Sylvester-Bradley R., 2008. Effects of variety and fertiliser nitrogen on alcohol yield, grain yield, starch and protein content, and protein composition of winter wheat. J. Cereal Sci., 48: 46-57.

Klír J., Vegricht J., 2009. The production and use of farm fertilizers in the CR. Proceedings of 15th International Conference Reasonable Use of Fertilizers.

Kramer T., 1979. Environmental and genetic variation for protein content in winter wheat (*Triticum aestivum* L.). Euphytica, 28: 209-218.

López-Bellido L., Fuentes M., Castillo J.E., López-Garrido F.J., 1998. Effects of tillage, crop rotation and nitrogen fertilization on wheat-grain quality grown under rainfed Mediterranean conditions. Field Crop Res., 57: 265-276.

Ndayegamiye A., Côté D., 1988. Effect of long-term pig slurry and solid cattle manure application on soil chemical and biological properties. Canadian J. Soil Sci., 69: 39-47.

Pratt P.F., Broadbent F.E., Martin J.P., 1973. Using organic wastes as nitrogen fertilizers. In: Eghball B., Wienhold B.J., Gilley J.E., Eigenberg R.A. 2002. Mineralization of Manure Nutrients. Biological Systems Engineering: Papers and Publications, Paper 139.

Rao A.C.S., Smith J.L., Jandhyala V.K., Papendick R.I., Parr J.F., 1993. Cultivar and climatic effects on the protein content of soft white winter wheat. In: Graybosch R.A., Peterson C.J., Baenziger P.S., Shelton D.R. 1995. Environmental modification of hard red winter wheat flour protein composition. Publications from USDA-ARS/UNL Faculty, Paper 917.

Rharrabti Y., Royo C., Villegas D., Aparicio N., García del Moral L.F., 2003. Durum wheat quality in Mediterranean environments I. Quality expression under different zones, latitudes and water regimes across Spain. Field Crop Res., 80: 123-131.

Rieger S., Richner W., Streit B., Frossard E., Liedgens M., 2008. Growth, yield, and yield components of winter wheat and the effects of tillage intensity, preceding crops, and N fertilisation. Europ. J. Agron., 28: 405-411.

Singh S., Kumar Gupta A., Kumar Gupta S., Kaur N., 2010. Effect of sowing time on protein quality and starch pasting characteristics in wheat (*Triticum aestivum* L.) genotypes grown under irrigated and rain-fed conditions. Food Chem., 122: 559-565.

Yu H., Ding W., Luo J., Geng R., Cai Z., 2012. Long-term application of organic manure and mineral fertilizers on aggregation and aggregate-associated carbon in a sandy loam soil. Soil Till. Res., 124: 170-177.

Zhao J., Zhou L., 2011. Combined application of organic and inorganic fertilizers on black soil fertility and maize yields. Journal of Northeast Agricultural University (English edition), 18: 24-29.

Zhengchao Z., Zhuoting G., Shangguan Z., Fuping Z., 2013. Effects of long-term repeated mineral and organic fertilizer applications on soil organic carbon and total nitrogen in a semi-arid cropland. Europ. J. Agron., 45: 20-26.