EFFECT OF ORGANIC AND MINERAL FERTILIZERS ON YIELD PARAMETERS AND QUALITY OF WHEAT GRAIN*

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The aim of this study was to evaluate winter wheat grain qualitative and yield parameters after the application of different organic and mineral fertilizers at two sites in the Czech Republic (S1 – Lukavec, S2 – Prague-Suchdol). For the purpose of this paper grain yield (GY, t ha^{-1}), thousand kernel weight (TKW, g), bulk density (BD, g l^{-1}), grain crude protein content (CP, %), and falling number (FN, s) were determined with regard to the CSN 461100-2 (2001) standard for food wheat. Significantly highest values of GY and BD at both sites and of CP at S2 were observed after the use of nitrogen in mineral form. At S1, significantly highest values of FN were obtained after the use of mineral fertilizers in combination with straw. The required limit of BD for food wheat was met for all fertilization treatments, while that of CP only at S2 by treatments with mineral nitrogen fertilizers. At S2, a strong correlation between all evaluated traits was registered. Low correlation was found at S1 between TKW and other evaluated traits.

grain quality; nitrogen; wheat; fertilizer; protein content; bulk density

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INTRODUCTION

Nitrogen is the most important element to achieve stable high grain yields (Delogu et al., 1998; Shi et al., 2012) and it is essential for improving grain quality of wheat (Hussain et al., 1996; McKenzie et al., 2005; Pan et al., 2006). In 2014 wheat was grown at 34% of the total sown area of the Czech Republic (CSO, 2014). Both high yield and good and stable quality are important features in today's wheat market (López-Bellido et al., 2001; Flaete et al., 2005). Wheat quality is influenced by the interaction of a number of factors, including cultivar, soil, climate, cropping practices, and grain storage conditions. The performance of many qualitative characteristics depends greatly on environmental conditions, which result in different expression of grain quality from site to site (López-Bellido et al., 2001; Rharrabti et al., 2003). Predictions of grain quality for the prospective wheat harvest would be of considerable value to grain buyers in aiding purchasing decisions, and to farmers to help optimize late-season agronomy (Smith, Gooding, 1999). Grain protein content, perhaps the most important quality feature for wheat, is known to be influenced by climatic parameters and N availability, cultivar, nitrogen fertilizer rate, time of nitrogen application, residual soil nitrogen, and available moisture during grain filling. Nitrogen application combined with a better distribution of N during the wheat growth cycle significantly improves grain protein content (Abad et al., 2004; Garrido-Lestache et al., 2004; Ma et al., 2009). Relationships between qualitative parameters appear to be influenced by climatic conditions during grain filling. Thus, depending on temperatures and water input during this phase, correlation coefficients between some qualitative parameters, such as thousand kernel weight (TKW) and protein content (CP), can be either positive, negative or close to zero (Rharrabti et al., 2003).

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Table 1. Characteristics of experimental sites

Site	S1 – Lukavec	S2 – Prague-Suchdol
Location	49°33´23″N, 14°58´39″E	50°7´40″N, 14°22´33″E
Altitude (m a.s.l.)	610	286
Average annual temperature (°C)	7.7	9.1
Average annual precipitation (mm)	666	495
Soil type	Cambisol	Haplic Chernozem
Soil texture	sandy loam	silt loam
pH (KCl)	4.89	7.22
P Mehlich 3 (mg kg^{-1})	160	110
K Mehlich 3 (mg kg^{-1})	220	246
Mg Mehlich 3 (mg kg^{-1})	98	194
Ca Mehlich 3 (mg kg^{-1})	1393	7509

Table 2. Rates of nutrients N-P-K (kg ha^{-1}) during crop rotation cycle

Treatment	Fertilization	Potatoes	Winter wheat	Spring barley
1	Control	–	–	–
2	SS[1]	330-207-44	–	–
3	FYM[1]	330-102-307	–	–
4	N[2]	120-0-0	140-0-0	70-0-0
5	NPK[2]	120-30-100	140-30-100	70-30-100
6	N[2] + ST[1,3]	138-6-47	140-0-0	70-0-0

SS = sewage sludge, FYM = farmyard manure, N = N in mineral fertilizers, ST = spring barley straw

[1]P and K in organic fertilizers – average dose taking into account nutrient content in organic fertilizers

[2]mineral fertilizers: N – calcium ammonium nitrate (27% N), P – triple super phosphate (21% P), K – potassium chloride (50% K)

[3]5 t ha^{-1} spring barley straw

The objective of this paper was to evaluate the influence of different organic and mineral fertilizers on yield and qualitative parameters of winter wheat grain and to investigate the relationship between these traits.

MATERIAL AND METHODS

The two-year experiment was established at two sites of the Czech Republic with different soil and climatic conditions: S1 (Lukavec) and S2 (Prague-Suchdol) (Table 1). A simple rotation included three crops in the order: potatoes, winter wheat, spring barley (each year all crops were grown). Six treatments were evaluated: (1) control, (2) sewage sludge (SS), (3) farmyard manure (FYM), (4) N in mineral fertilizers (N), (5) NPK, and (6) N in mineral fertilizers + spring barley straw (N + ST). For mineral nitrogen fertilization, calcium ammonium nitrate was used. Organic fertilizers were applied only to the potatoes in the crop rotation. The dose of nitrogen was for winter wheat divided into two parts (regeneration and production fertilization). The amount of applied nutrients is given in Table 2. The area of experimental plot was 60 m^2. The grown variety of winter wheat was Alana, which is characterized as a late variety with baking quality A.

Data were collected in the years 2013 and 2014. Dry matter grain yield (GY, t ha^{-1}), thousand kernel weight (TKW, g), bulk density (BD, g l^{-1}), grain crude protein content (CP, %), and falling number (FN, s) were determined. All the qualitative parameters were assessed using two random samples from each treatment. Thousand kernel weight was calculated 2 × 500 seeds using an electronic calculator (DIPOS, SP JZD Libun, Czech Republic) and the seeds were weighted with a prescribed accuracy. Bulk density was determined using a laboratory meter model 1938 (Meopta, Přerov, Czech Republic). Grain was milled using the device PSY MP40 (Mezos, Hradec Králové, Czech Republic) with 0.8 mm sieve size. Afterwards falling number was determined on a device Falling number 1400 (Perten, Hägesten, Sweden) (CSN ISO 3093, 2007). Grain samples for determination of total nitrogen were homogenized on a laboratory cutting mill SM 100 (Retsch, Haan, Germany) and measured following the Kjeldahl

Table 3. Dry matter grain yield (GY, t ha^{-1})

	Site S1 – Lukavec		Site S2 – Prague-Suchdol	
	2013	2014	2013	2014
Control	1.33	3.10	4.66	3.90
SS	3.09	5.13	7.05	5.50
FYM	2.55	5.22	6.05	5.25
N	4.76	7.10	7.96	6.29
NPK	4.88	7.46	7.20	6.49
N + ST	5.22	8.82	7.47	6.71

SS = sewage sludge, FYM = farmyard manure, N = N in mineral fertilizers, NPK = calcium ammonium nitrate + triple super phosphate + potassium chloride, ST = spring barley straw

Table 4. Thousand kernel weight (TKW, g)

	Site S1 – Lukavec				Site S2 – Prague-Suchdol			
	2013	CV	2014	CV	2013	CV	2014	CV
Control	43.54^{a}	1.31	48.70^{ab}	0.67	51.36^{ab}	3.52	51.19^{a}	1.15
SS	45.28^{b}	1.19	49.81^{b}	0.44	53.86^{bc}	2.12	54.34^{b}	0.98
FYM	44.56^{ab}	1.18	48.78^{ab}	0.10	53.72^{bc}	1.23	54.69^{b}	0.50
N	43.57^{a}	0.70	48.98^{ab}	0.65	56.01^{c}	1.12	55.93^{b}	1.80
NPK	45.15^{b}	0.97	47.98^{a}	1.77	54.97^{c}	1.96	56.04^{b}	1.51
N + ST	44.34^{ab}	0.88	51.04^{c}	0.83	54.22^{abc}	1.53	55.22^{b}	1.24

CV = coefficient of variation, SS = sewage sludge, FYM = farmyard manure, N = N in mineral fertilizers, NPK = calcium ammonium nitrate + triple super phosphate + potassium chloride, ST = spring barley straw

$^{a–c}$ values in the column with the same letter were not significantly different at $P < 0.05$

Table 5. Bulk density (BD, g l^{-1})

	Site S1 – Lukavec				Site S2 – Prague-Suchdol			
	2013	CV	2014	CV	2013	CV	2014	CV
Control	784.5^{a}	4.86	777.7^{a}	2.08	**755.8^{a}**	7.83	**759.5^{a}**	4.84
SS	785.4^{a}	2.61	768.9^{b}	1.70	769.4^{b}	4.20	780.4^{b}	3.57
FYM	787.3^{a}	0.71	773.4^{c}	1.62	764.0^{ab}	4.45	781.8^{b}	3.35
N	797.5^{b}	3.60	785.1^{d}	1.02	783.8^{c}	1.16	791.0^{c}	2.19
NPK	793.2^{b}	2.46	784.7^{d}	3.07	778.8^{c}	1.18	792.4^{c}	2.33
N+ST	804.8^{b}	0.57	796.1^{e}	0.62	778.3^{c}	2.02	791.3^{c}	6.64

CV = coefficient of variation, SS = sewage sludge, FYM = farmyard manure, N = N in mineral fertilizers, NPK = calcium ammonium nitrate + triple super phosphate + potassium chloride, ST = spring barley straw

values of BD lower than 760 g l^{-1} are bolded

$^{a–d}$values in the column with the same letter were not significantly different at $P < 0.05$

method on a device VAPODEST 50s (Gerhardt GmbH & Co. KG, Königswinter, Germany). The observed nitrogen content was multiplied by a coefficient (for baking wheat 5.7) to obtain the crude protein content in the grain (CSN 461011-18, 2003).

Statistical evaluation of the results was performed using STATISTICA software package (Version 12, 2012) with the Main effects ANOVA followed by the Tukey's test at the level of significance $P < 0.05$. Coefficients of variability (CV) were calculated as the ratio of the standard deviation to the mean. Coefficients of correlation (r) between the assessed traits were presented in a correlation matrix both for sites and years.

RESULTS

The highest GY values were after the application of mineral fertilizers (5.0 t ha^{-1} at S1 and 7.5 t ha^{-1} at S2 in 2013, and 7.8 t ha^{-1} at S1 and 6.2 t ha^{-1} at S2

Table 6. Protein content (CP, %)

	Site S1 – Lukavec				Site S2 – Prague-Suchdol			
	2013	CV	2014	CV	2013	CV	2014	CV
Control	**8.14[a]**	1.07	**7.49[a]**	0.76	**9.90[a]**	1.52	**9.47[a]**	1.20
SS	**8.62[a]**	2.00	**7.05[b]**	0.00	12.00[bc]	2.40	**11.49[b]**	0.00
FYM	**9.52[b]**	0.12	**7.05[b]**	0.81	**10.28[a]**	0.30	**10.84[b]**	2.63
N	**9.72[b]**	1.90	**8.14[c]**	0.70	11.87[b]	1.67	12.44[c]	0.92
NPK	**8.47[a]**	1.37	**7.92[c]**	2.16	12.39[bc]	0.27	12.40[c]	0.46
N+ST	**9.60[b]**	2.23	**8.99[d]**	1.90	12.56[c]	1.06	12.28[c]	2.32

CV = coefficient of variation, SS = sewage sludge, FYM = farmyard manure, N = N in mineral fertilizers, NPK = calcium ammonium nitrate + triple super phosphate + potassium chloride, ST = spring barley straw

values of CP lower than 11.5% are bolded

[a–d]values in the column with the same letter were not significantly different at $P < 0.05$

Table 7. Falling number (FN, s)

	Site S1 – Lukavec				Site S2 – Prague-Suchdol			
	2013	CV	2014	CV	2013	CV	2014	CV
Control	261[a]	2.44	322[ab]	2.80	246[a]	2.30	242[a]	4.55
SS	307[b]	2.08	314[a]	5.41	273[b]	2.34	275[ab]	12.02
FYM	315[bc]	1.12	336[ab]	3.87	264[ab]	0.00	266[ac]	0.38
N	318[bc]	1.11	357[abc]	0.84	271[b]	1.31	298[ab]	4.37
NPK	310[b]	0.91	365[b]	1.37	270[b]	2.62	333[bc]	5.41
N+ST	334[c]	1.91	393[c]	3.31	270[b]	0.26	339[b]	0.88

CV = coefficient of variation, SS = sewage sludge, FYM = farmyard manure, N = N in mineral fertilizers, NPK = calcium ammonium nitrate + triple super phosphate + potassium chloride, ST = spring barley straw

values of FN lower than 220 s are bolded

[a–c]values in the column with the same letter were not significantly different at $P < 0.05$

Table 8. Trait correlation

Site, year	Trait	GY	TKW	BD	CP
S1 2013	TKW	0.22	–	–	–
	BD	**0.87**	–0.15	–	–
	CP	0.52	–0.22	0.65	–
	FN	**0.82**	0.35	**0.73**	**0.79**
S1 2014	TKW	0.40	–	–	–
	BD	0.79	0.38	–	–
	CP	**0.80**	0.50	**0.98**	–
	FN	**0.91**	0.37	**0.95**	**0.92**
S2 2013	TKW	**0.94**	–	–	–
	BD	**0.96**	**0.94**	–	–
	CP	**0.89**	**0.72**	**0.87**	–
	FN	**0.93**	**0.86**	**0.81**	**0.83**
S2 2014	TKW	**0.93**	–	–	–
	BD	**0.98**	**0.99**	–	–
	CP	**0.98**	**0.95**	**0.97**	–
	FN	0.93	0.78	0.86	0.88

S1 = site Lukavec, S2 = site Prague-Suchdol, GY = dry matter grain yield, TKW = thousand kernel weight, BD = bulk density, CP = grain crude protein content, FN = falling number

bolded correlation coefficients (*r*) were significant at $P < 0.05$

in 2014 (Table 3). The lowest average yields in the control treatment at S1 were 1.3 t ha^{-1} in 2013 and 3.1 t ha^{-1} in 2014, and at S2 4.7 t ha^{-1} in 2013 and 3.7 t ha^{-1} in 2014. Thousand kernel weight is one of the yield parameters. The lowest values of TKW at S2 were observed in the control treatment, whereas mineral fertilized treatments reached the highest values (Table 4). Higher values were achieved at S2 than at S1. At S1, the highest values were found for SS treatment in 2013 and for N + ST treatment in 2014. The limit of bulk density for food wheat is 760 g l^{-1} according to the standard CSN 461100-2 (2001). The required limit was not reached at S2 in control treatment in both years. The significantly highest values were observed after mineral nitrogen fertilization at both sites. Values of BD were higher at S1 if compared to S2 (Table 5). According to the standard CSN 461100-2 (2001), the minimal requirement of CP for food wheat is 11.5%. This limit was not achieved by any treatment at S1 and by control treatment and FYM at S2 in both years and by SS treatment in 2014. The highest values for CP after the application of nitrogen in mineral form were determined at S2 (Table 6). The lowest values of FN were observed in control treatment at both sites and in SS treatment at S1 in 2014 (Table 7). All treatments exceeded the limit for falling number, which is 220 s. At S1, the highest values for FN were obtained after mineral fertilizers in combination with straw. A strong correlation between all traits was found at S2 (Table 8). At S1, the correlation between TKW and other traits was low. At this site a strong correlation was found between GY and BD, FN, between FN and BD, and between FN and CP in 2013 and between GY and BD, CP, FN, between BD and CP, FN, and between FN and CP in 2014.

DISCUSSION

The highest influence of nitrogen fertilizer application was observed at S1, where the average yield for N + ST treatment was higher by about 292% in 2013 and 185% in 2014 in comparison to control. Similarly, as in the study with barley of Shejbalová et al.

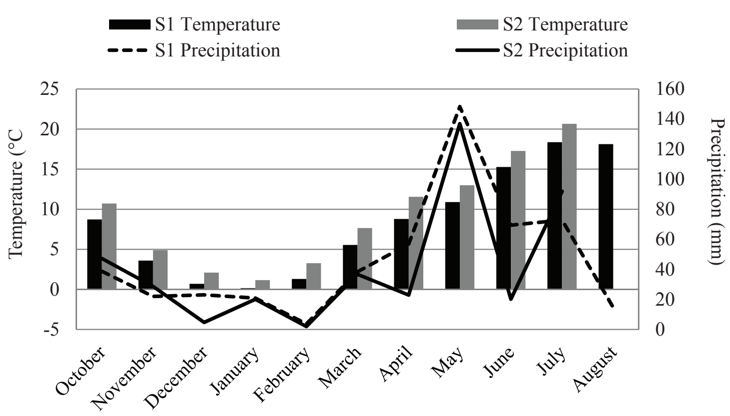

Fig. 1. Average precipitation (mm) and average air temperature (°C) in the growing season of winter wheat 2012/2013 at S1 and S2 location

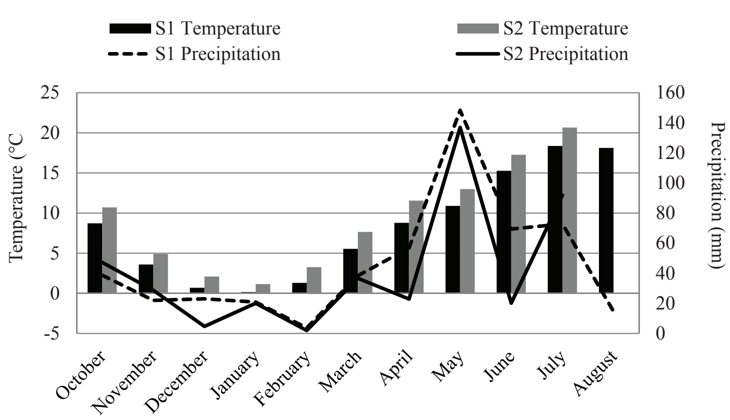

Fig. 2. Average precipitation (mm), average air temperature (°C) in the growing season of winter wheat 2013/2014 at S1 and S2 location

(2014), the present experiment confirmed a tendency of yield increases at the low fertile location after mineral nitrogen application. Similar tendency of yield increases after mineral nitrogen application on the low fertile location in this experiment with barley were obtained (Shejbalová et al., 2014). Thousand kernel weight is greatly determined by climatic conditions, particularly high temperature during the final phase of grain filling can negatively affect this yield parameter (López-Bellido et al., 1998; Rharrabti et al., 2003), which may explain why there were high differences between years at S1. At S1, the average temperature in July 2013 was 19.1 °C (Fig. 1), in this year lower values of TKW were observed. The average temperature in July 2014 was 18.4 °C (Fig. 2), which resulted in higher levels of TKW at this site. Significantly higher values of BD were registered at both sites after the application of mineral fertilizers compared to organic fertilizers and control treatment, and exhibited highly significant positive correlation with grain yield. López-Bellido et al. (1998) arrived to the same conclusion. The highest values of CP after the application of nitrogen in mineral form were obtained at S2. Kozlovský et al. (2009) achieved high values of CP after application of 150 kg N ha^{-1} in mineral form, which is in line with our experiment. Similarly, Ducsay, Ložek (2004) reported that nitrogen fertilizing to the level of 140 kg N ha^{-1} positively influenced formation of CP with the highest increment. The minimal value of the N content for baking wheat for any of the treatments was achieved at S1, which is assumed to be caused by the low natural fertility of this location. At S2, similar low values of CP were observed in previous years 1997–2012 (Buráňová et al., 2015). Values of FN highly differed between years and sites, which is confirmed by the findings of Kozlovský et al. (2010) stating that FN is highly influenced by site conditions and year. In our experiment, the correlations between traits were mostly high positive. Only in 2013 at S1 the correlations between BD and TKW and between CP and TKW were slightly negative. These results are in contradiction with the results of Kučerová (2005) proving in an experiment with winter wheat grain that high baking quality of grain is negatively correlated with grain yield. Similarly, as the study by Wang (2008), the present study did not reveal a clear correlation between FN and TKW, however there was a positive relation of CP to FN.

CONCLUSION

The results obtained in this study demonstrate that N treatments markedly affect grain yield and qualitative parameters of winter wheat. At both sites the highest grain yields were achieved in treatments with mineral nitrogen. At S2, if compared to S1, higher values of thousand kernel weight were found. At both sites the highest values of thousand kernel weight were found for treatments with mineral nitrogen, at S1 also for the sewage sludge treatment. The highest bulk density values were observed after mineral nitrogen fertilizing if compared to organic fertilizing and control treatment. Sufficient values of protein content were reached only at S2 for treatments with mineral fertilizers and in 2013 for sewage sludge treatment. At S1, all the treatments reached the required limit for food wheat. At S2, a high correlation between all parameters was found. More balanced results between years were detected at S2 than at S1.

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