Mineral and organic fertilization efficiency in long-term stationary experiments

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ABSTRACT

In long-term stationary experiments under different soil-climatic conditions, an influence of mineral and organic fertilization on yield of winter wheat, spring barley and potato tubers was evaluated. Statistically significantly lowest grain yields of winter wheat (4.00 t/ha) and spring barley (2.81 t/ha) were obtained in non-fertilized plots at all experimental sites. In the case of potatoes, the lowest yield of dry matter (5.71 t/ha) was recorded in the control plot, but the result was not statistically significant. The manure-fertilized plot gave the average yield of wheat higher by 30%, of barley by 22%. Application of sewage sludge resulted in wheat yield higher by 41% and barley yield higher by 26% over control. On average, application of sewage sludge and manure increased the yield of potatoes by 30% over control. The highest yield was obtained after application of mineral fertilizers; average yield increased by 59, 50 and 36% in winter wheat, spring barley and potatoes, respectively. No statistically significant differences among the plots with mineral fertilizers were observed. At different sites, the yield of studied crops varied; however, the effect of fertilization on yield increments was similar at all experimental sites except for Lukavec. It is the site with the lowest natural soil fertility, and it showed the highest effect of the applied fertilizers.

Keywords: long-term field experiment; winter wheat; spring barley; potatoes; manure; sewage sludge; mineral fertilizers

One of the most important intensification factors of crop production is plant nutrition and fertilization. This factor has a significant impact on yield and quality of harvested products. Cereals belong among crops that are important from the viewpoint of growing area. The ratio of winter wheat on agricultural soils presents an important part; it is an intensive crop with high demands and its yield is limited with appropriate agrotechnical equipment, site conditions and especially nutrition. Another important crop is spring barley; it is sensitive to weather conditions in spring period (Trnka et al. 2007). Barley can compensate weather changes mainly at balanced fertilization. Potatoes are described as a crop with high precrop value which is, however, influenced by the type of fertilization. Stable yields are obtained from potatoes fertilized with organic fertilizers, especially farmyard manure.

Yet, most agricultural companies in the Czech Republic limit fertilization to usage of mineral nitrogen fertilizers; the amount of nutrients uptaken by main and secondary products is often higher than the input of nutrients to soil in form of organic and mineral fertilizers. Comparison of conditions in the Czech Republic and European countries was described by Chloupek et al. (2004). A positive effect of farmyard manure application on crop yield was observed in numerous studies (Vaněk et al. 1997a, Balík et al. 1999, Barzegar et al. 2002). Nevertheless, many agricultural companies have no animal production or have significantly decreased production of farmyard fertilizers. Organic fertilization then may be replaced with straw left in the field after the harvest of cereals, although the effect of straw application on yield reported in literature is rather low (Powlson et al. 1985, Thomsen and Jensen 1994,

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Procházková et al. 2003). Yet, a positive influence of straw on soil properties was observed (Christensen 1986, Powlson et al. 1987, Ocio et al. 1991, Černý et al. 2003). An alternative to the application of organic matter and nutrients may be fertilization with stabilized sewage sludges from waste water treatment plants. Numerous publications describe advantages of sewage sludge application to agricultural soils, mainly for its influence on yield of fertilized crops (Christie et al. 2001), but also with reference to soil properties (Johansson et al. 1999, Balík et al. 2007). Compared to organic fertilizers, the reported influence of mineral, mainly nitrogen fertilizers on grain yield of cereals is often higher (Hansen 1996).

The effect of fertilization on crop yield was observed in many studies; the trials however show that the strength of the effect may differ. Soil conditions, climatic factors and weather conditions in a given year also significantly influence yield production (Benjamin et al. 2003, Cai and Qin 2006). Locally-specific effects of field trials are often a limiting factor for drawing correct conclusions. A short-term effect can be inconsistent with the results of long-term observations. Hence, agricultural practices need the results of both short-term and long-term experiments. Field trials are the most relevant source of such information and may help to balance the inconsistence of outputs of e.g. pot experiments (Leikam et al. 1983).

The aim of this work is to evaluate long-term effects of different fertilizers on yield of winter wheat, spring barley and potato tubers in different soil-climatic conditions.

MATERIAL AND METHODS

The effect of fertilization on grain yield of winter wheat and spring barley was observed in precise long-term field trials. These trials were established in 1996 at five sites of the Czech Republic with different soil-climatic conditions: Červený Újezd, Hněvčeves, Humpolec, Lukavec, Praha - Suchdol (Table 1). Within the trials three crops were rotated in the following order: potatoes, winter wheat, spring barley. Because of the agrotechnical conditions of the Červený Újezd site, potatoes as the experimental crop were replaced there by silage maize. The size of experimental plots was 60 m^2, at Červený Újezd site it was 80 m^2. The trial comprised 7 treatments: 1. no fertilization (control); 2. sewage sludges (SS); 3. farmyard manure (FYM); 4. half dose of farmyard manure + N in mineral nitrogen fertilizers (FYM + N); 5. mineral nitrogen fertilizers (N); 6. NPK in mineral fertilizers (NPK); 7. straw of spring barley + N in mineral nitrogen fertilizers (ST + N). Organic fertilizers – sewage sludges (SS), farmyard manure (FYM) and straw (ST) were always applied in autumn (October) to potatoes (maize). Mineral phosphorus and potassium fertilizers were applied to each crop in autumn; mineral nitrogen fertilizers were applied to potatoes and spring barley in spring prior to crop establishment. In the case of winter wheat the nitrogen dose was divided into halves, the first one was applied as regenerative fertilization, the second one as productive fertilization (Table 2). The content of nitrogen was 140 kg N/ha for wheat and 70 kg N/ha for spring barley. The NPK treat-

Table 1. Experimental sites characteristics

Site	Červený Újezd	Hněvčeves	Humpolec	Lukavec	Suchdol
Location	50°4'22''N, 14°10'19''E	50°18'46''N, 15°43'3''E	49°33'16''N, 15°21'2''E	49°33'23''N, 14°58'39''E	50°7'40''N, 14°22'33''E
Altitude (m a.s.l.)	410	265	525	610	286
Mean annual temperature (°C)	7.7	8.2	7.0	7.7	9.1
Mean annual precipitation (mm)	493	573	665	666	495
Soil type	Luvisol	Luvisol	Cambisol	Cambisol	Chernozem
Soil texture	loam	clay-loam	sandy-loam	sandy-loam	loam
pH ($CaCl_2$)	6.5	5.9	5.1	4.3	7.5
C_{ox} (%)	1.7	1.6	2.3	1.7	2.6
CEC ($mmol^{(+)}$/kg)	145	179	159	128	230
P Mehlich III (mg/kg)	100	84	90	124	91
K Mehlich III (mg/kg)	80	150	190	213	230
Mg Mehlich III (mg/kg)	110	130	100	80	240
Ca Mehlich III (mg/kg)	3600	3600	1300	1100	9000

Table 2. Application rates of nutrients (kg/ha) – (3-year cycle)

Treatment	Potatoes			Wheat			Barley		
	N	P	K	N	P	K	N	P	K
Control	–	–	–	–	–	–	–	–	–
Sewage sludge (SS)	330[1]	201[2]	55[2]	0	0	0	0	0	0
Farmyard manure (FYM)	330[1]	118[2]	374[2]	0	0	0	0	0	0
FYM + N[3]	165[1]	59[2]	187[2]	110	0	0	55	0	0
N[3]	120	0	0	140	0	0	70	0	0
NPK[3]	120	30	100	140	30	100	70	30	100
Straw ST + N[3]	138	6[2]	47[2]	140	0	0	70	0	0

[1]nitrogen as total nitrogen in organic fertilizers; [2]average yearly dose, depends on nutrient content in organic fertilizers (Table 3); [3]mineral fertilizers: N – calcium ammonium nitrate (27% N); P – triple super phosphate (21% P); K – potassium salt (50% K)

ment of winter wheat and spring barley included phosphorus at a rate of 30 kg P/ha (Triple Super Phosphate) and potassium at a rate of 100 kg K/ha (60% potassium salt). At the other treatments, the dosage of P and K depended on the content of nutrients in applied organic fertilizers (Table 3). At all sites, the sewage sludges from the Waste Water Treatment Plant in Prague-Troja were used. Plant harvesting was done with an experimental combine harvester. The average size of harvested plots was 20 m^2 in Humpolec and Hněvčeves, 40 m^2 in Lukavec and Suchdol and at Červený Újezd site it was 60 m^2. The obtained fresh matter yield was converted into dry matter content for spring barley, winter wheat and potato. Samples for dry matter determination were dried at 105°C. The yield data sets were recalculated to dry matter yield per one hectare area.

The results were assessed using the ANOVA statistical analysis. The differences in yield caused by the type of fertilization at individual sites for the whole experimental period (1997–2008) were compared. To evaluate the obtained results, the STATISTICA programme was used.

RESULTS AND DISCUSSION

The presented results were obtained during the whole period of the trial, i.e. from 1997 to 2008. The aim being to document effects of different forms of fertilization, the graphical forms use relative values related to the control non-fertilized treatment. Variability of the obtained results is quantified using the coefficient of variation. Higher variability is influenced mainly by the interannual yield variability at individual sites.

Potatoes and maize. Average yields of potatoes and silage maize dry matter are shown in Table 4. The lowest yield was obtained at control plots at all sites. Lower values of potato tubers dry matter, namely 4.89 and 5.17 t/ha were recorded at control plots at Suchdol and Hněvčeves sites, respectively. At Humpolec and Lukavec sites, the yields of potato tubers dry matter were 6.30 and 6.49 t/ha, respectively. Site conditions and type of fertilization have a great effect on potato tubers yield formation as well as on their qualitative parameters (Hamouz et al. 2005). Compared with cereals, potatoes gave a lower yield increment as

Table 3. Average characteristics of organic fertilizers and their dry matter (DM) application rates

	Dose (t/ha/y)	DM content (%)	Nutrients content (% DM)				
			N	P	K	Ca	Mg
Sewage sludge (SS)	9.00	30.6	3.66	2.23	0.61	3.00	0.78
FYM Červený Újezd	14.48	30.3	2.48	0.81	2.14	2.28	0.58
FYM Hněvčeves	16.63	25.6	2.15	0.75	2.49	2.51	0.59
FYM Humpolec	14.92	24.6	2.28	0.72	2.24	1.55	0.62
FYM Lukavec	17.77	26.3	1.90	0.63	2.72	1.71	0.51
FYM Suchdol	16.83	34.2	2.05	0.76	1.94	2.20	0.60
Straw (ST)	5.00	95.0	0.35	0.11	0.93	0.49	0.04

Table 4. Mean dry matter yield (t/ha) of potato tubers (silage maize) at different sites (average per 12 years)

Treatment	Červený Újezd[1]		Hněvčeves[2]		Humpolec[2]		Lukavec[2]		Suchdol[2]	
	yield	s	yield	s	yield	s	yield	s	yield	s
Control	12.47	2.34	5.17	1.51	6.30	1.90	6.49	1.97	4.89	1.48
SS	15.32	2.45	7.55	2.50	8.02	2.35	8.56	2.70	5.94	1.67
FYM	14.09	3.56	7.67	2.89	8.65	2.61	8.34	2.73	5.84	1.38
FYM + N	13.98	3.33	7.02	2.31	8.17	2.23	7.92	2.42	5.77	1.42
N	14.70	3.78	8.14	2.89	9.02	2.24	9.77	2.95	5.54	1.51
NPK	15.89	4.14	8.16	3.60	8.04	1.80	10.18	3.04	6.12	1.63
ST + N	14.95	3.40	8.18	2.44	8.15	2.23	9.18	2.58	5.63	1.44

[1]yield of silage maize DM; [2]yield of potato tubers DM

a response to fertilization. At Suchdol site, the average yield, compared to control, was higher by 13–18% at plots treated with nitrogen fertilizers, by 19% with manure treatment, by 21% with sewage sludges and by 25% at plots treated with NPK fertilizer (Figure 1). Similar results were obtained at Hněvčeves and Humpolec sites, where the yield increments were even higher. In Hněvčeves, the increase of yield at plots treated with half dose of manure was 36% over control. At plots with manure and sewage sludges, the increase was 46 and 48%, respectively. The other treatments gave an increase by 58% compared to control. At Humpolec site, the highest increments, compared to control, were recorded at N treatment (43%) and FYM treatment (37%). The other treatments resulted in an increase of yield over control within the range of 27–29%. At Lukavec site, the yield increment was lowest at treatment with half dose of farmyard manure, i.e. 22% over control; the treatment with manure and sewage sludges resulted in an increase by 28 and 32%, respectively. Plots amended with mineral fertilizers showed yield higher by 41–57% than control. In the case of potatoes, we observed high interannual variability of yield in the course of the trial, and thus the specific differences in yields were not regarded as statistically significant (Figure 2). Interannual yield variability is also influenced by type of fertilization; the treatments with mineral fertilizers showed higher yield variability compared to organic fertilizers. Similar results are reported by Haberle and Ivičic (2006). Average yield of silage maize dry matter at Červený Újezd site was 12.47 t/ha at non-fertilized plot. Plots fertilized with manure had yield higher by 12–13% than control. Nitrogen application increased the yield by 18% and N with straw by 20%. The application of sewage sludges resulted in an increase of silage maize dry matter by 23% compared to control. The greatest effect was recorded at application of NPK fertilizers, with the yield increased by 27% over control.

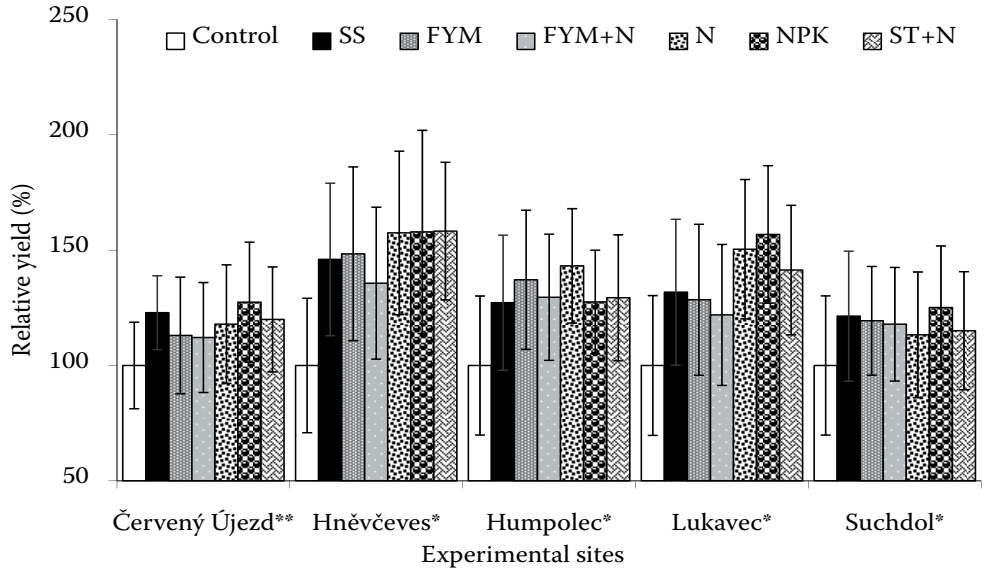

Figure 1. Relative dry matter yield (%) of potato tubers* (silage maize**) at different sites

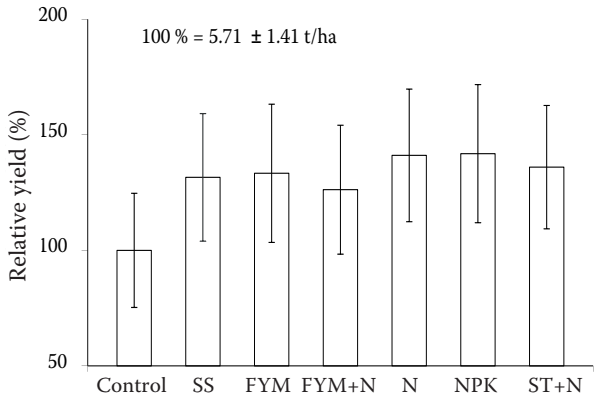

Figure 2. Relative dry matter yield (%) of potato tubers – all sites average per 12 years

Winter wheat. Average yields of winter wheat at all experimental sites are shown in Table 5. Winter wheat grain yield was affected by site conditions, year and fertilization treatment.

The lowest yields were obtained at all sites at the non-fertilized control plots; the significantly lowest average yield, namely 2.74 t/ha, was recorded at Lukavec site, the highest average yield of 4.92 t/ha was recorded at Humpolec site. The Lukavec site trials, compared to the other sites, gave the lowest values of wheat grain yield at plots treated with manure and sewage sludges. Both the treatments had the average yield of 3.80 t/ha for the whole experimental period. At other sites, the differences in grain yield of winter wheat among fertilized plots were not significant; however, the treatments with only manure or sewage sludges always resulted in lower yields. Lower yields of winter wheat after farmyard manure application in long-term trials were described by Berzsenyi et al. (2000), who compared the effect of manure application and combinations of NPK fertilization. Although the effect of manure application on yield is lower than that of NPK fertilization, usage of farmyard manure brings about other positive aspects, especially to soil properties. It serves, for instance as a source of organic matter, it increases stability of soil aggregates, influences soil water regime, activity of soil microorganisms and amount of microbial biomass (Raun et al. 1993, Karlen and Doran 1993, Černý et al. 2008). A greater effect on grain yield of cereals is reported at combined application of manure and mineral fertilizers (Manna et al. 2005). It is in compliance with our results; the average grain yield of winter wheat at application of manure and mineral nitrogen fertilizers was higher by 0.59–2.47 t compared to manure application only.

In a comparison of treatments with sewage sludges and manure, a greater effect on yield was recorded at sewage sludges application; the average yield was higher by 0.41 t/ha compared to manure application. The results indicate that the treatment with sewage sludges had a positive effect on winter wheat yield, which is in accordance with the results of other long-term trials (Mantovi et al. 2005). As for the application of mineral nitrogen fertilizers, the obtained values of winter wheat grain yield were relatively balanced; the differences in yield were influenced mainly by site soil-climatic conditions. Average yield of treatments with mineral nitrogen fertilizers ranged between 5.42 and 6.01 t/ha at Červený Újezd and Suchdol sites, between 6.04 and 6.50 t/ha at Lukavec site and between 6.95 and 7.24 t/ha at Humpolec and Hněvčeves sites.

In a comparison of effects of different types of fertilization on grain yield of winter wheat, a significant difference was recorded between the control and fertilized plots. Only at Suchdol site, this difference was not statistically significant. Inasmuch as it is a fertile site with good reserve of available nutrients, the effect of fertilization was rather low. At more fertile sites, the absence of fertilization results in a much slower yield reduction compared to less fertile sites (Vaněk et al. 1997b). This is documented by the results from

Table 5. Mean dry matter yield (t/ha) of winter wheat grain at different sites (average per 12 years)

Treatment	Červený Újezd		Hněvčeves		Humpolec		Lukavec		Suchdol	
	yield	s	yield	s	yield	s	yield	s	yield	s
Control	3.39	0.53	4.54	1.22	4.92	0.74	2.74	0.48	4.43	1.05
SS	5.07	0.74	7.01	1.65	6.82	0.98	3.80	0.96	5.53	1.61
FYM	4.79	0.97	6.64	1.07	5.96	1.00	3.80	0.82	5.00	1.84
FYM + N	5.54	0.89	7.32	1.26	6.91	1.33	6.27	0.70	5.59	1.41
N	5.65	0.75	7.24	1.17	6.95	1.25	6.41	0.68	5.75	1.45
NPK	5.55	0.67	7.17	1.18	7.13	1.16	6.50	0.74	6.01	1.38
ST + N	5.42	0.99	7.23	1.24	7.20	1.44	6.04	0.76	5.57	1.47

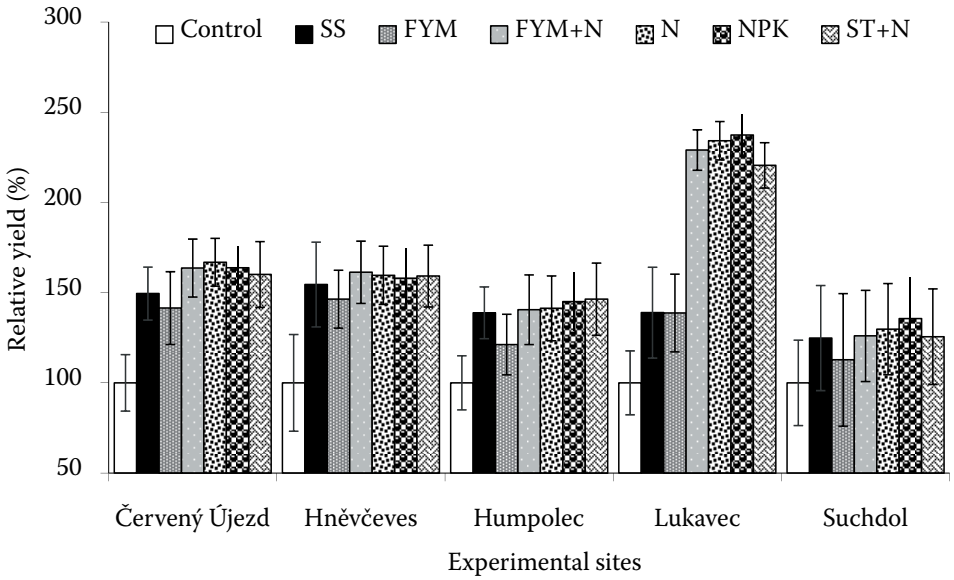

Figure 3. Relative yield of winter wheat grain (%) at different sites

Lukavec site; the treatments with mineral fertilizers resulted in yields higher by 120 to 137% over control (Figure 3). At the other sites, the yields at plots treated with mineral fertilizers were higher by 40–66% compared to control. Application of sewage sludges increased grain yields by 25% at Suchdol site, by 39% at Humpolec and Lukavec sites, and the highest increase was recorded at Červený Újezd and Hněvčeves sites, where the increase reached 50 and 55%, respectively. A lower effect on yield was observed in the case of manure application (Figure 4); the increase was higher by 13, 21 and 39% at Suchdol, Humpolec and Lukavec sites. The greatest effect of manure application on winter wheat grain yield was recorded at Červený Újezd and Hněvčeves sites, where the yield increased by 41 and 46%, respectively.

Spring barley. Average yield of spring barley at studied sites is shown in Table 6. Spring barley grain

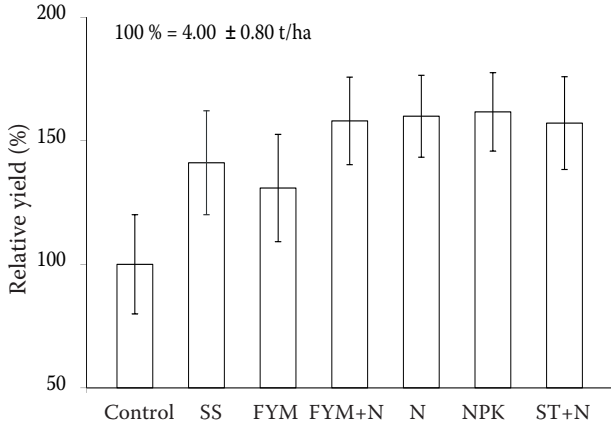

Figure 4. Relative yield (%) of winter grain – all sites average per 12 years

yield was, as that of winter wheat, influenced by site conditions, year and fertilization treatment. However, a higher interannual variability of yields was observed at spring barley. In a comparison of effect of fertilization on spring barley grain yield, the lowest values were obtained at all sites at control non-fertilized plots; the lowest average yield was 1.92 t/ha in trials at Lukavec site, whereas the highest average grain yield in control was obtained at Suchdol and Hněvčeves sites, with the values of 3.27 and 3.30 t/ha. At Červený Újezd and Humpolec experimental sites, the average grain yields of spring barley at control plots were 2.73 and 2.85 t/ha, respectively. As in the case of winter wheat, the lowest yield of fertilized plots was obtained at Lukavec site; average spring barley yield after treatment with sewage sludges reached 2.39 t/ha, whereas it was 2.59 t/ha in the case of manure application. The treatments with mineral fertilizers in Lukavec resulted in average values of 3.39–3.57 t/ha. Among fertilized plots no statistically significant differences were obtained.

At other sites, the differences among spring barley grain yields in fertilized plots were not significant, either; however, lower yields were always obtained in treatments with only manure or sewage sludges compared to plots with mineral fertilization. Yield increment of spring barley after application of different doses of manure was also described by Hansen (1996); differences among yields were not significant, whereas he reported significantly higher yield after the application of NPK.

In a comparison of plots treated with sewage sludges and manure, the application of sewage sludges had a greater effect on yield; the average values were by 0.22 t/ha higher than with manure

Table 6: Mean dry matter yield (t/ha) of spring barley grain at different sites (average per 12 years)

Treatment	Červený Újezd		Hněvčeves		Humpolec		Lukavec		Suchdol	
	yield	s	yield	s	yield	s	yield	s	yield	s
Control	2.73	0.71	3.30	0.47	2.85	0.81	1.92	0.31	3.27	0.80
SS	3.80	0.91	4.30	0.91	3.61	0.80	2.39	0.54	3.68	0.87
FYM	3.65	0.89	3.88	0.78	3.57	0.71	2.59	0.59	3.42	0.91
FYM + N	4.27	0.79	4.53	1.37	4.52	0.57	3.44	0.59	4.26	0.71
N	4.22	0.63	4.53	1.49	4.43	0.73	3.52	0.75	4.13	1.05
NPK	4.40	0.77	5.15	1.71	4.70	0.69	3.57	0.84	4.30	0.81
ST + N	4.22	1.03	4.78	1.30	4.60	0.89	3.39	0.61	4.39	0.81

application. If these results are compared to wheat values the yield reaction of spring barley to sludge application is lower; it is caused by a longer period after sludges application, as barley was the last crop in rotation. A fast process of mineralization of organic matter from sewage sludges releases nutrients for crops after application and the influence of fertilization in following years decreases (Antolín et al. 2005). The half-life of nitrogen in organic bonds of sewage sludges is reported to be one year (Hall 1984). This is documented by the results from the sites with light soils; at Humpolec site, yields of the plots treated with sewage sludges and manure were equal, and at Lukavec site, the long-term yield of the plot treated with sewage sludges was by 0.20 t/ha lower compared to manure. Organic matter applied in the farmyard manure is more stable compared to sewage sludges (Saviozzi et al. 1999) and has a greater effect on the content of organic C and N in soil (Nedvěd et al. 2008).

In a comparison of plots treated with mineral nitrogen fertilizers, the obtained grain yields of spring barley were relatively stable; the differences in yields were influenced mainly by site soil-climatic conditions. Values of average yields at plots treated with mineral nitrogen fertilizers ranged between 4.52–5.15 t/ha at Humpolec and Hněvčeves sites, between 4.13–4.40 t/ha at Červený Újezd and Suchdol sites, and 3.44–3.57 t/ha at Lukavec site.

In a comparison of effect of fertilization on spring barley grain yield, a significant difference was obtained between control and fertilized plots. The effect of fertilization was, however, lower than in the case of winter wheat. A greater difference between control and fertilized plots was observed at Červený Újezd, Humpolec and Lukavec sites; the difference was statistically significant only between control and application of mineral fertilizers (Figure 5). At plots treated with organic fertilizers, higher yield, compared to control, was

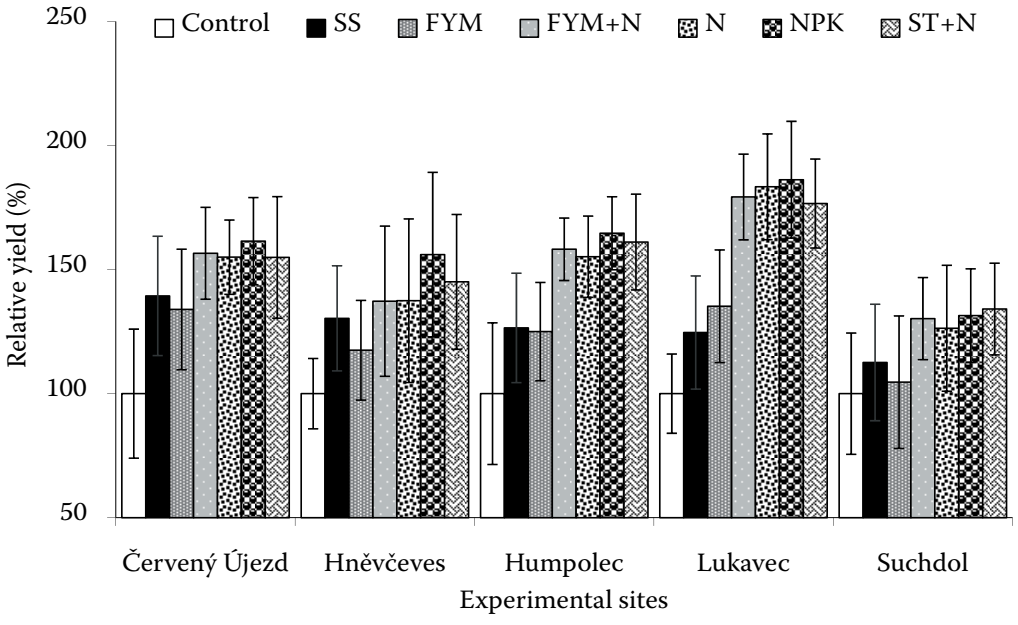

Figure 5. Relative yield of spring barley grain (%) at different sites

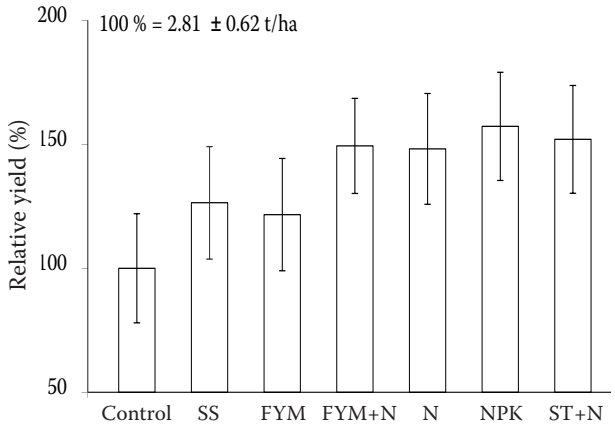

Figure 6. Relative yield (%) of spring barley grain – all sites average per 12 years

obtained only in the case of sewage sludge treatments. Their application increased grain yield by 13, 25, 27 and 30% at Suchdol, Lukavec, Humpolec and Hněvčeves sites, respectively; the greatest effect was recorded at Červený Újezd site, where the yield increased by 39%. A lower influence was observed at manure application. The yield, compared to control, was higher by 5, 18, 25, and 34% at Suchdol, Hněvčeves, Humpolec and Červený Újezd sites, respectively. The greatest effect on spring barley grain yield after manure application was obtained at Lukavec site, where the yield increased by 35% over control.

In treatments with mineral fertilizers the increment of spring barley grain yield was higher. As in the case of winter wheat, the grain yield of spring barley showed a strongest reaction to applied fertilizers at Lukavec site where the treatments with mineral fertilizers resulted in an increase by 77 to 86% over control. The lowest effect of mineral fertilization was obtained at Suchdol site; the average yield was by 26–34% higher than control. At other sites, the plots fertilized with mineral fertilizers gave the yield higher by 37–65% compared to control.

The results of the evaluation of cereals show a more significant effect on yield at plots treated with mineral fertilizers; the most important nutrient was applied nitrogen. A lower effect was reported after farmyard manure and sewage sludges application (Figures 4 and 6). This effect was more important for winter wheat; in the case of spring barley, with the longer interval after application, the yield decreased. At all sites, the lowest yields were obtained at non-fertilized plots.

The overall comparison of all three studied crops and all sites indicates the importance of combining mineral and organic fertilization. The yields after application of organic fertilizers only (though at relatively high doses) did not reach the values obtained at balanced mineral fertilization. No significant differences between farmyard manure and sewage sludges treatment were recorded in either crop (providing that the amount of supplied nitrogen was the same).

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