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# EFFECT OF LONG-TERM N, P, AND K FERTILIZER APPLICATION ON THE GRAIN YIELD OF SPRING BARLEY GROWN IN DIFFERENT SOIL AND CLIMATE CONDITIONS: RESULTS FROM ČÁSLAV, LUKAVEC AND IVANOVICE 2005–2008

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The effect of N, P and K application on the grain yield of spring barley in 2005–2008 within three long-term field experiments (Čáslav, Ivanovice, Lukavec) was evaluated. In these experiments, nitrogen at rates of 50, 77.6, 105 and 132.5 kg N ha$^{-1}$, phosphorus at rates of 14 and 29.4 kg P ha$^{-1}$ and potassium at 59 and 96.4 kg K ha$^{-1}$ was annually applied to the treat-ments during that period. Four years summarizing shows that the optimal application rate of fertilizers resulting in a grain yield above 6 t ha$^{-1}$ was 105 kg N ha$^{-1}$, 14 kg P ha$^{-1}$ and 96.4 kg K ha$^{-1}$ in Čáslav and above 7 t ha$^{-1}$ was 78 kg N ha$^{-1}$, 14 kg P ha$^{-1}$ and 59 kg K ha$^{-1}$ in Ivanovice. The rate of N 132.5 kg ha$^{-1}$ in Lukavec increased the grain yield more than threefold (from 1.94 to 6.12 t ha$^{-1}$) and probably was not sufficient to obtain the highest grain yield in this locality. No significant difference was recorded between grain yields in P and K fertilizing treatments in any of the three stations. The key result is that degraded chernozem (in Ivanovice) and greyic phaeozem (in Čáslav) demonstrate a high and long-term stable natural fertility, but yields of spring barley of low productive sandy-loamy Cambisol is strongly affected by high rates of nitrogen application.

Key words: long-term fertilizer experiments, grain yield, nitrogen, phosphorus, potassium, spring barley

## INTRODUCTION

Yield stability is an important indicator of productivity and sustainability in agricultural land (Kubát et al. 2003). As follows from many studies (Chmielewski & Köhn 1999; Kubát et al. 2003; Haberle & Mikysková 2006; Váňová et al. 2006; Kunzová & Hejcman 2009; Trnka et al. 2009; Hejcman & Kunzová 2010), the yield variability of main cereals is affected by many factors. Spring barley is one of the most important cereal crops in Europe. In the Czech Republic it is the second most widespread crop on arable land with an average annual production of 4.1 t ha$^{-1}$ grain in 2000–2009 (Anonymous 2009), and cropping area of 320.207 ha representing 8.5% of total agricultural land in 2009 (Anonymous 2009). The effect of climatic factors as well as soil condition and preceding crop on the grain yield of spring barley in the Czech Republic and Slovakia in the past years has been documented in many papers (e.g. Halás et al. 1983; Strnad 1983; Kopecký 1987; Voňka et al. 1987). Long-term fertilizer experiments with spring barley are also still running worldwide (Soane & Ball 1998; Eltun et al. 2002; Anonymous 2006; Machado et al. 2007; Vogeler et al. 2009). In these experiments, primarily the nitrogen management was studied, because nitrogen, especially ammonium nitrate depreciated malting quality, increased the content of starch and nitrogen substances, and decreased the content of albumin in the grain (Baethgen et al. 1995). On the other hand, the rate of nitrogen mineral fertilizers 100

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N kg ha$^{-1}$ increased the grain yield of spring barley from 3.3 to 4.5 t ha$^{-1}$ in long-term cereal experiments (CBARC) in the USA (Machado et al. 2007) and the rate of 150 N kg ha$^{-1}$ from 1.94 to 5.15 t ha$^{-1}$ in long-term experiments on barley in Scotland (Soane & Ball 1998). In the Hoosfield Barley long-term experiments, recent yields continue to show that the rate of 144 kg N ha$^{-1}$ increased the yield of spring barley from 0.6 to 7.8 t ha$^{-1}$ in 2002–2005, respectively (Anonymous 2006). No significant effect of N application on spring barley yield was reported by Riley (1998) and Mengel et al. (2006). Furthermore, phosphorus fertilizer application was very important to the yield of spring barley as well as interaction between N and P (Sinebo et al. 2002; Anonymous 2006; Machado et al. 2007). Potassium application only slightly affected the grain yield (Anonymous 2006), but positively influenced the malting quality of barley (Zimolka 2006). To study the effect of crop rotation and the efficiency of fertilizer application on main crops produced in the Czech Republic, a series of long-term experiments was established by Baier at five different sites in 1955 (Baier & Kristan 1970).

The aim of this study was to investigate how the yield of spring barley is affected by long-term N, P and K fertilizer application in different climate and soil conditions in crop rotation with a 56% share of cereals.

## MATERIALS AND METHODS

*Experimental design*

The long-term crop rotation experiments in Čáslav, Ivanovice and in Lukavec were established in 1955 in different climatic and soil conditions (Table 1), according to the same design. Experimental fields were arranged in four neighbouring strips. Each field strip consisted of 12 fertilizer treatments replicated four times (Fig. 1). Each fertilizer treatment was replicated in the experimental field 16 times (192 monitoring plots). The individual plot size of 8 m × 8 m (9 m × 9 m in Čáslav) and only central 5 m × 5 m plot was

| a | | b | | c | | d | |
|---|---|---|---|---|---|---|---|
| 11 | 12 | 21 | 22 | 15 | 16 | 23 | 24 |
| 13 | 14 | 23 | 24 | 11 | 12 | 25 | 26 |
| 15 | 16 | 25 | 26 | 13 | 14 | 21 | 22 |
| 25 | 26 | 15 | 16 | 21 | 22 | 13 | 14 |
| 21 | 22 | 11 | 12 | 23 | 24 | 15 | 16 |
| 23 | 24 | 13 | 14 | 25 | 26 | 11 | 12 |

Fig. 1. Arrangement of treatments in field experiments. Letters [a–d] indicate complete randomized blocks and Arabic numbers indicate individual treatments

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Site description

| Station | Čáslav | Ivanovice | Lukavec |
|---|---|---|---|
| Location | 49°53´29´´ N, 15°45´00´´ W | 49°18´51´´N, 17°06´20´´ W | 49°33′30″ N, 14°58′51″ W |
| Cropping area | sugar beet | sugar beet | potato |
| Climatic region | warm, slightly humid | warm, slightly arid | slightly warm, humid |
| Altitude | 225 [m] | 263 [m] | 620 [m] |
| Precipitation | 555 [mm] | 556 [mm] | 686 [mm] |
| Temperature | 8.9 °C | 8.4 °C | 6.8 °C |
| Soil type | Greyic Phaeozem | Loamy Degraded Chernozem | Stagno Gleyic Cambisol |
| Clay content | 20.7% | 22.1% | 13.4% |
| Thickness of humus horizon | 40-50 [cm] | 40 [cm] | 18-25 [cm] |

used for experimental purposes. Except for control treatment 21, farmyard manure (FYM) at the rate of 40 t ha$^{-1}$ was applied every four years in the autumn to root crop. Mineral fertilizers at the rate of 30 kg N ha$^{-1}$ (N1); 60 kg N ha$^{-1}$ (N2); 90 kg N ha$^{-1}$ (N3) and 50 kg K ha$^{-1}$ (K2) to spring barley were applied in spring before sowing. In the period 2005–2008 the preceding crop was maize and the cultivar of spring barley, Calgary,

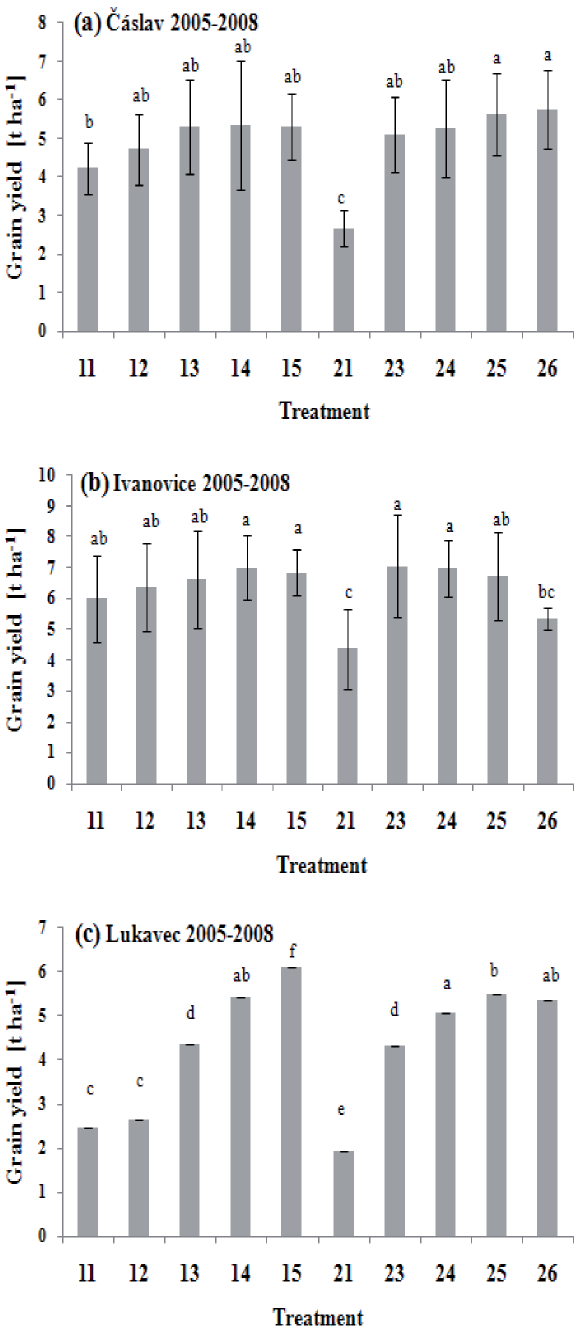


Fig. 2. Effect of individual treatments on the grain yield of spring barley in Čáslav (a), Ivanovice (b) and Lukavec (c) 2005–2008

Vertical lines indicate standard error of the mean (SE). Treatment with the same letter were not significantly different

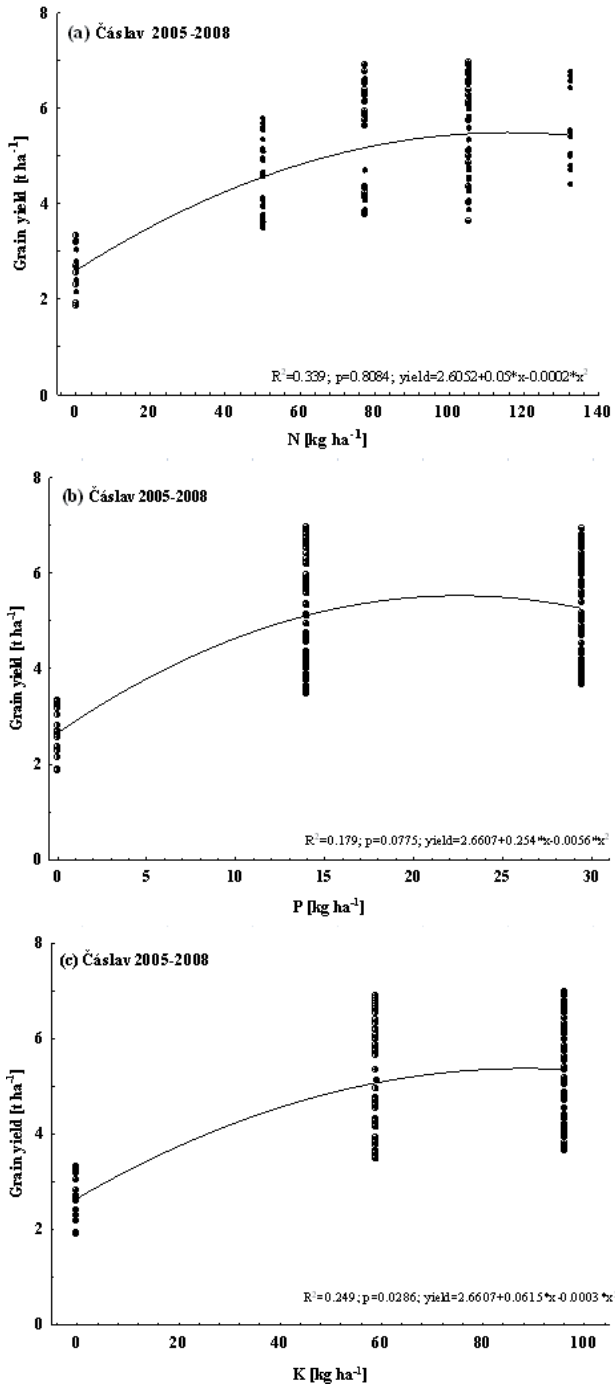


Fig. 3. Effect of N (a), P (b) and K (c) application rate on the grain yield of spring barley in Čáslav 2005–2008

was used. A list of fertilizer treatments used is given in Table 3 and Table 4. Soil chemical properties in selected treatments were analyzed according to the Mehlich III method. Soil samples were taken as a mixture of ten sub-samples from the plough layer. The organic C content was determined by the NIRS method in an accredited national laboratory. To measure pH ($CaCl_2$), a 0.2 M solution was used and 20 g of soil was mixed with 50 ml of the solution (Table 2).

Table 2

Results of basic soil properties in 2006

| Station | pH [$CaCl_2$] | P [mg kg$^{-1}$] | K [mg kg$^{-1}$] | Mg [mg kg$^{-1}$] | C org [%] |
|---|---|---|---|---|---|
| Čáslav | | | | | |
| 11 | 6.9 | 50 | 117 | 150 | 1.42 |
| 14 | 6.8 | 116 | 160 | 147 | 1.50 |
| 21 | 6.7 | 31 | 106 | 149 | 1.28 |
| 24 | 6.7 | 21 | 98 | 113 | 1.46 |
| Ivanovice | | | | | |
| 11 | 7.2 | 151 | 260 | 194 | 1.82 |
| 14 | 7.1 | 194 | 308 | 210 | 1.96 |
| 21 | 7.4 | 112 | 186 | 212 | 1.71 |
| 24 | 7.2 | 123 | 241 | 207 | 1.84 |
| Lukavec | | | | | |
| 11 | 6.2 | 77 | 108 | 103 | 1.47 |
| 14 | 5.8 | 205 | 130 | 98 | 1.53 |
| 21 | 6.2 | 38 | 73 | 98 | 1.29 |
| 24 | 6.0 | 34 | 81 | 96 | 1.49 |

P and K concentrations were determined by Mehlich III extraction

Table 3

Amounts of N, P, K [kg ha$^{-1}$] applied directly to spring barley

| Coding | Treatment | N | P | K |
|---|---|---|---|---|
| 11 | FYM | 0 | 0 | 0 |
| 12 | FYM+PK | 0 | 0 | 50 |
| 13 | FYM+N1PK | 30 | 0 | 50 |
| 14 | FYM+N2PK | 60 | 0 | 50 |
| 15 | FYM+N3PK | 90 | 0 | 50 |
| 21 | Control | 0 | 0 | 0 |
| 23 | FYM+N1 | 30 | 0 | 0 |
| 24 | FYM+N2 | 60 | 0 | 0 |
| 25 | FYM+N2P | 60 | 0 | 0 |
| 26 | FYM+N2K | 60 | 0 | 50 |

Table 4

Mean amounts of N, P, K [kg ha$^{-1}$] applied annually to the treatments in 2005–2008

| Coding | Treatment | N | P | K |
|---|---|---|---|---|
| 11 | FYM | 50.0 | 14.0 | 59.0 |
| 12 | FYM+PK | 50.0 | 29.4 | 96.4 |
| 13 | FYM+N1PK | 77.6 | 29.4 | 96.4 |
| 14 | FYM+N2PK | 105.0 | 29.4 | 96.4 |
| 15 | FYM+N3PK | 132.5 | 29.4 | 96.4 |
| 21 | Control | 0 | 0 | 0 |
| 23 | FYM+N1 | 77.6 | 14.0 | 59.0 |
| 24 | FYM+N2 | 105.0 | 14.0 | 59.0 |
| 25 | FYM+N2P | 105.0 | 29.4 | 59.0 |
| 26 | FYM+N2K | 105.0 | 14.0 | 96.4 |

Treatment abbreviations: FYM, farmyard manure; N1–N3, ammonium nitrate (27% N); P, superphosphate (19 % $P_2O_5$); K, potassium chloride (60 % $K_2O$)

*Statistics*

One-way and factorial ANOVA in Statistica 5.0 software (StatSoft, Tulsa) tests were used to evaluate the grain yield data. In the case of significant ANOVA results, the Tukey HSD Post Hoc test was used to evaluate the differences between individual treatments. Polynomial and linear regression was used to analyze the effect of the N, P and K application rate on grain yield.

## RESULTS

The grain yield in Čáslav ranged from 2.66 to 5.76 t ha$^{-1}$ in the control (treatment 21) and 26 treatment respectively (Fig. 2a). The effect of fertilizer treatment on grain yield was significant (DF = 13, $F$ = 11.9, $P$ < 0.001). An increase of grain yield was recorded in N, P and K application up to rates of 122, 23 and 91 kg ha$^{-1}$ respectively (Fig. 3). The highest grain yield above 6 t ha$^{-1}$ was recorded in treatment 26 where approximately 105 kg N ha$^{-1}$, 14 kg P ha$^{-1}$ and 96.4 kg K ha$^{-1}$ were applied. The grain yield in Ivanovice ranged from 4.36 to 7.06 t ha$^{-1}$ in treatments 21 and 23 respectively (Fig. 2b). The effect of fertilizer treatment on the grain yield was significant (DF = 12, $F$ = 7.8, $P$ < 0.001). An increase in grain yield was recorded at N, P and K application up to rates of 95, 27 and 74 kg ha$^{-1}$ respectively (Fig. 4). The highest grain yield above 7 t ha$^{-1}$ was recorded in treatment 23 where approximately 78 kg N ha$^{-1}$, 14 kg P ha$^{-1}$ and 59 kg K ha$^{-1}$ were applied. The grain yield in Lukavec ranged from 1.94 to 6.12 t ha$^{-1}$ in treatments 21 and 15 respectively (Fig. 2c). The effect of fertilizer treatment on grain yield was significant (DF = 34, $F$ = 311, $P$ < 0.001). Except for N application, grain yield increase was recorded in P and K application up to rates of 24 and 96 kg ha$^{-1}$ respectively (Fig. 5). The highest grain yield above 6 t ha$^{-1}$ was recorded approximately for 132 kg N ha$^{-1}$, 29 kg P ha$^{-1}$ and 96 kg K ha$^{-1}$ application in treatment 15 respectively. The effect of soil and climatic conditions on grain yield in selected fertilizer treatments is illustrated in Table 5. Significantly the lowest grain yield in 80% of samples compared to Čáslav and Ivanovice was recorded in Lukavec. The factorial measures ANOVA showed a significant effect of station (DF = 25, $F$ = 322, $P$ < 0.001), year (DF = 3, $F$ = 40, $P$ < 0.001) and station × year interaction (DF = 75 $F$ = 40, $P$ < 0.001) on grain yields in control treatments 21 (Fig. 6). The grain yield in individual years ranged from 2.03 to 3.27 t ha$^{-1}$ in 2008 and 2005 (Čáslav), from 2.99 to 5.69 t ha$^{-1}$ in 2007 and 2005 (Ivanovice) and from 1.58 to 2.15 t ha$^{-1}$ in 2008–2007 (Lukavec).

## DISCUSSION

In the locality of Čáslav, the optimal application rate of N, P and K resulting in a grain yield above 5.7 t ha$^{-1}$ was 105 kg N, 14 kg P, 96.4 kg K per ha (treatment 26). The optimal application rate in the locality of Ivanovice resulting in grain yield above 7.1 t ha$^{-1}$ was 77.6 N kg, 14 kg P and 96.4 kg K per ha (treatment 23). Based on the results of regression analyses, a further increase of N, P and K fertilizer rates do not result in increased grain yield in Čáslav and Ivanovice. The

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Effect of station on grain yields [t ha$^{-1}$] in selected fertilizer treatments in 2005–2008

| Station | Treatments | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 11 | 12 | 13 | 14 | 15 | 21 | 23 | 24 | 25 | 26 |
| Čáslav | 4.23$^{b}$ ± 0.16 | 4.72$^{b}$ ± 0.22 | 5.31$^{a}$ ± 0.31 | 5.35$^{a}$ ± 0.42 | 5.32$^{a}$ ± 0.21 | 2.66$^{b}$ ± 0.12 | 5.11$^{a}$ ± 0.24 | 5.27$^{a}$ ± 0.31 | 5.62$^{a}$ ± 0.26 | 5.76$^{a}$ ± 0.26 |
| Ivanovice | 6.01$^{c}$ ± 0.34 | 6.38$^{c}$ ± 0.35 | 6.64$^{b}$ ± 0.39 | 7.01$^{b}$ ± 0.26 | 6.85$^{c}$ ± 0.19 | 4.36$^{c}$ ± 0.33 | 7.06$^{b}$ ± 0.42 | 7.00$^{b}$ ± 0.23 | 6.74$^{b}$ ± 0.36 | 7.02$^{b}$ ± 0.24 |
| Lukavec | 2.47$^{a}$ ± 0.05 | 2.66$^{a}$ ± 0.06 | 4.37$^{a}$ ± 0.07 | 5.41$^{a}$ ± 0.07 | 6.12$^{b}$ ± 0.12 | 1.94$^{a}$ ± 0.07 | 4.34$^{a}$ ± 0.08 | 5.07$^{a}$ ± 0.11 | 5.50$^{a}$ ± 0.08 | 5.37$^{a}$ ± 0.09 |

Treatments with the same letter are not significantly different. Treatment abbreviations are given in table 3 and 4.
± value represents standard error of the mean (SE)

optimal application rate of P and K in Lukavec resulting in a grain yield above 6 t per ha was 29.4 kg P and 96.4 kg K per ha in treatment 15. In this locality the grain yield was highly affected by N application, because a rate of 77.6 kg N per ha doubled the grain yield and an increment of N rate to 32.5 kg N per ha trebled

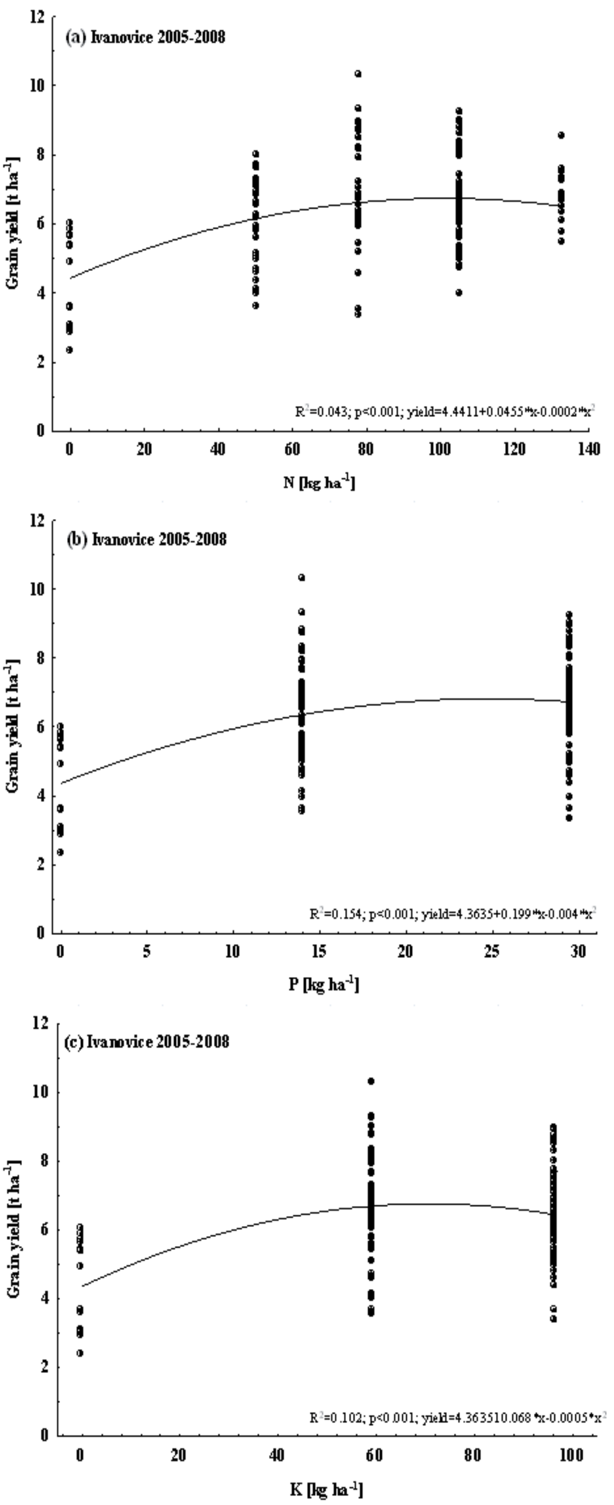

Fig. 4. Effect of N (a), P (b) and K (c) application rate on the grain yield of spring barley in Ivanovice 2005–2008

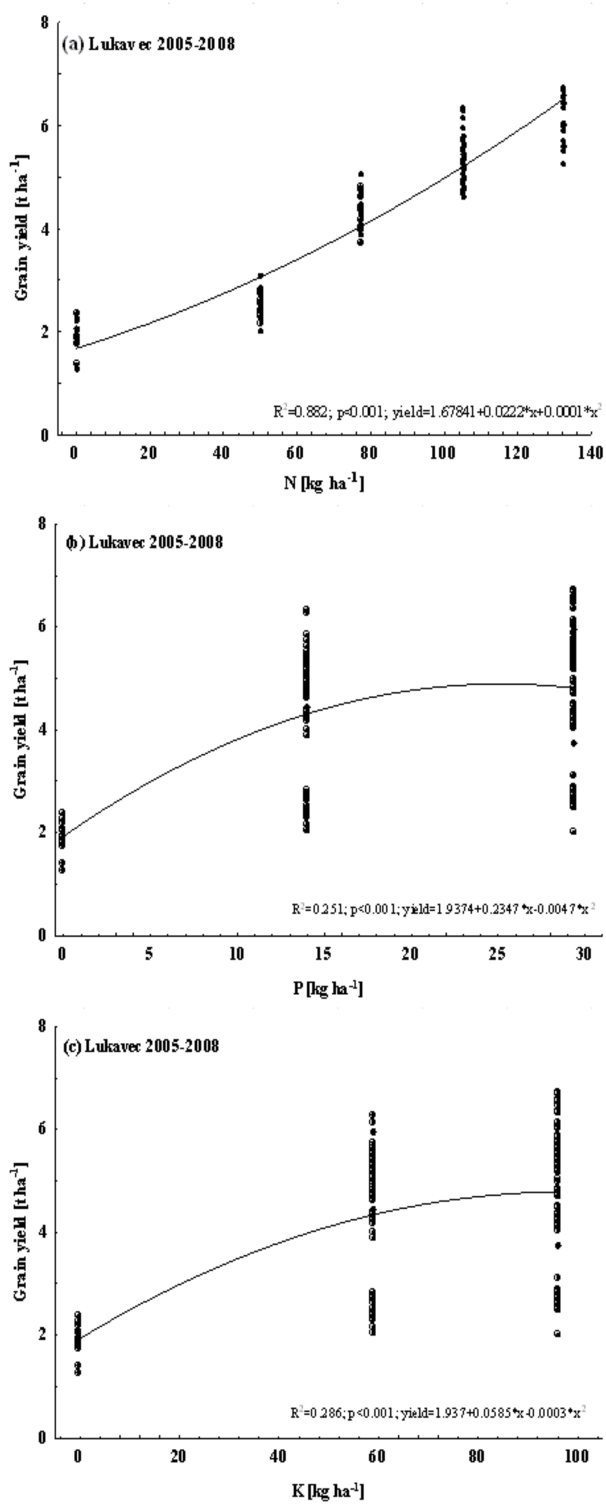

Fig. 5. Effect of N (a), P (b) and K (c) application rate on the grain yield of spring barley in Lukavec 2005–2008

the grain yield in comparison to unfertilized control. These results correspond to the results of Matějková and Kumhálová (2010) and Šrek et al. (2010), who reported that different rates of nitrogen fertilizer can increase utilization of production on a specific site. Soane and Ball (1998) in Scotland showed that the rate of 150 kg N $ha^{-1}$ increased the grain yield above 5 t $ha^{-1}$ or that 100 kg N $ha^{-1}$ was used by Machado et al. (2007) to achieve grain yield of approximately 4.5 t $ha^{-1}$. Anonymous (2006) and Vogeler et al. (2009) also showed the same effect in a similar experimental design as in our paper. On the other hand, the high requirement of nitrogen input in Lukavec indicates less sustainable soil and climatic conditions than Čáslav and Ivanovice (Kubát et al. 2003). In addition to full fertilizer treatment 15, in Lukavec, the yield of 6.12 t $ha^{-1}$ was significantly higher than the yield of 5.32 t $ha^{-1}$ in Čáslav. A possible explanation is that abiotic factors in Čáslav highly decreased the yields in comparison to other years (unpublished data from Čáslav). No significant differences were recorded in grain yields within P and K fertilizing treatments in any of the three stations. Similarly, the addition of 15 kg P $ha^{-1}$ in combination with 37 kg K $ha^{-1}$ (treatment 12) has had no significant effect on grain yield in any of the three stations. This result conforms with the study of Vogeler et al. (2009), but in contrast with studies which recorded the highly positive effect of a slight K addition on the grain yield (Jouany et al. 1996; Tan et al. 2007). Nevertheless, in Lukavec a slight addition of

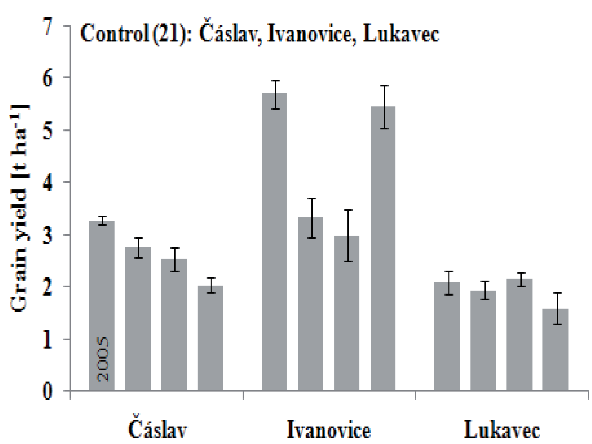


Fig. 6. Effect of year on the grain yield in individual station in control treatment 21 only

Vertical lines indicate standard error of the mean (SE). Treatment with the same letter were not significantly different

phosphorus above 15 kg P $ha^{-1}$ increased the grain yield approximately of 0.5 t $ha^{-1}$ in treatment 25. In control treatments, grain productions reached 46%, 62% and 36% of yield on full fertilizer treatment (26) in Čáslav, Ivanovice and Lukavec. These are comparable with the results of Strnad (1983) in Čáslav, Hejcman and Kunzová (2010) in Lukavec, and Kunzová and Hejcman (2009) in Ivanovice. However, high grain fluctuations were recorded between the years in individual control treatments in stations. For example, no significant effect of location on the grain yield was documented in 2006. This is conforms with many authors (Kubát et al. 2003; Chloupek et al. 2004; Kunzová & Hejcman 2009; Hejcman & Kunzová 2010). The possible explanation is that the total precipitation and air temperature in Ivanovice was relatively lower in comparison to other years (Anonymous 2010). The same apparent relationship between grain yield and precipitation and temperature was shown by Haberle and Mikysková (2006), Váňová et al. (2006), and Trnka et al. (2009).

## CONCLUSION

In the long-term crop and fertilizer experiment in Čáslav, Ivanovice and Lukavec, summarizing the 4 year results, the optimal application rate of fertilizers resulting in a grain yield above 6 t $ha^{-1}$ was 105 kg N $ha^{-1}$, 14 kg P $ha^{-1}$ and 96.4 kg K $ha^{-1}$ in Čáslav and above 7 t $ha^{-1}$ was 78 kg N $ha^{-1}$, 14 kg P $ha^{-1}$ and 59 kg K $ha^{-1}$ in Ivanovice. The rate of N 132.5 kg $ha^{-1}$ in Lukavec increased the grain yield more than threefold (from 1.94 to 6.12 t $ha^{-1}$) and probably was not sufficient to obtain the highest grain yield in this locality. No significant differences were recorded in grain yields in P and K fertilizing treatments in any of the three stations. The key finding is that degraded chernozem (in Ivanovice) and grey soil (in Čáslav) provide high and long-term stable conditions for spring barley yields, but yields of spring barley in low productive sandy-loamy Cambisol are strongly affected by high rates of nitrogen application. The above-mentioned fact primarily affects the profitability of spring barley cropping.

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