Evaluation of crop yield under different nitrogen doses of mineral fertilization

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ABSTRACT

Yields of winter wheat, winter rape and oats were evaluated in the field; the field was divided into the site-specific zones and treated with variable doses of nitrogen fertilizer in years 2004–2006. Measurements of the yields were carried out with a yield monitor placed in a combine harvester. The measured data were processed into the yield maps by means of ArcGIS 9.2 software. Variable application of fertilizer should balance yield potential of the field. Generally, total yield variability on the field after the application of various doses of experimental fertilizer was similar in the years 2004 (11.3%), 2005 (14.7%) and 2006 (11.7%) in comparison with the year 2003 (25.02%). Variable application of nitrogen in the site-specific zones, created on the basis of the yield levels, decreased the yield variability in comparison with the uniform dose. Different doses of nitrogen fertilizer also enabled to increase utilization of production potential of the experimental field.

Keywords: crop yield variability; site-specific zone; variable dose of fertilizer; winter wheat; winter rape; oats

The main purpose of field experiments is to compare effectiveness of different ways of nitrogen fertilization. Precision is the principal requirement, but estimation of error is also important. Yield is influenced by many factors such as pests and soil fertility. If these factors are not taken into account, the extraneous variability may lead to erroneous comparisons. Proper field design and statistical evaluation of date will help to minimize this problem (Hatfield 2000). Precision agriculture may be defined as the application of information technology to problems in crop production (Lowenberg-DeBoer 2000). The basic hypothesis for precision agriculture is that the optimum doses of inputs to a crop vary spatially within a field (Lark and Wheeler 2003). Berry et al. (2005) proposed that precision conservation should be a science contributing to the sustainability of our biosphere in this century and the effectiveness of such approaches depends on ability to synchronize plant nitrogen demand with its supply and the ability to apply favoured compositions and dosages of N.

The technology that is the most utilized in precision agriculture is the yield monitoring. However, it is much more suited for large, regularly shaped fields than for small or irregularly shaped fields, particularly those in hilly regions. Georeferenced values may also be collected at these sites of traditional descriptors of plant and soil properties. Other data involving precision agriculture technology less costly to acquire than yield monitor values, such as soil electrical conductivity (Corwin and Lesch 2005) and remotely sensed image data (Moran et al. 1997), may be available as a supplement of the traditional plant and soil descriptors. Multifactorial spatial statistical techniques that were developed for the analysis of site-specific data (Plant et al. 1999, Roel and Plant 2004a,b) may then be applied to determine the management practices and to obtain high yields in a given region. The landscape is divided into multiple fields, each of which is managed in a certain way and is measured at a given number of points (Roel et al. 2007). These fields vary among themselves and also an individual field is not homogenous in its physical properties. The farmers apply management actions (e.g. fertilizer levels, pest control intensities, irrigation levels) that vary among the

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fields and possibly also within them. As a result of both the varying field conditions and the varying management practices the fields produce yields that vary across the landscape. The farmers apply different management practices partly because of different approaches to farming and partly because of their knowledge of the conditions of the individual fields and of the weather conditions in a given year.

On the basis of the previously published findings, the main goal of our investigation was to determine crop yield variation in the field and to evaluate effectiveness of nitrogen rate applications on the selected site-specific zones with different area and initial crop yield variability. The study should contribute to selection of the most suitable site-specific zones according to previous yield characteristics.

MATERIALS AND METHODS

The research was carried out in the field at a pilot farm (latitude 50°05'N, longitude 14°20'E) 340 m above sea level in Prague, the Czech Republic. The slope of the experimental field is 3–7°, the exposition is south and the depth of arable soil is 30 cm. The experimental field represents Orthic Luvisol soil, average precipitation of 472 mm and average temperature of 8.5°C per year. Since 2001, there was the following crops rotation: sugar beet was grown in 2001, spring barley in 2002, winter wheat in 2003 and 2005, winter rape in 2004 and oats in 2006. The field is managed by site-specific management system since 2004. The field soil was sampled at points measured by GPS in regular grid 40 × 40 m. Soil samples were analyzed by Mehlich III method. The content of total nitrogen (N_t), potassium (K), phosphorus (P), magnesium (Mg), calcium (Ca), organic carbon (C_{org}) and pH were determined and an influence of site specific data on crop yield was found.

At first, the field was fertilized in a uniform way in 2001, 2002 and 2003. Since 2004, the field was divided into the site-specific zones for variable doses of nitrogen. During growing season the three different rates of N fertilizer were applied. The field was treated with the same regenerative dose of nitrogen. Different productive and qualitative doses of nitrogen were applied during the

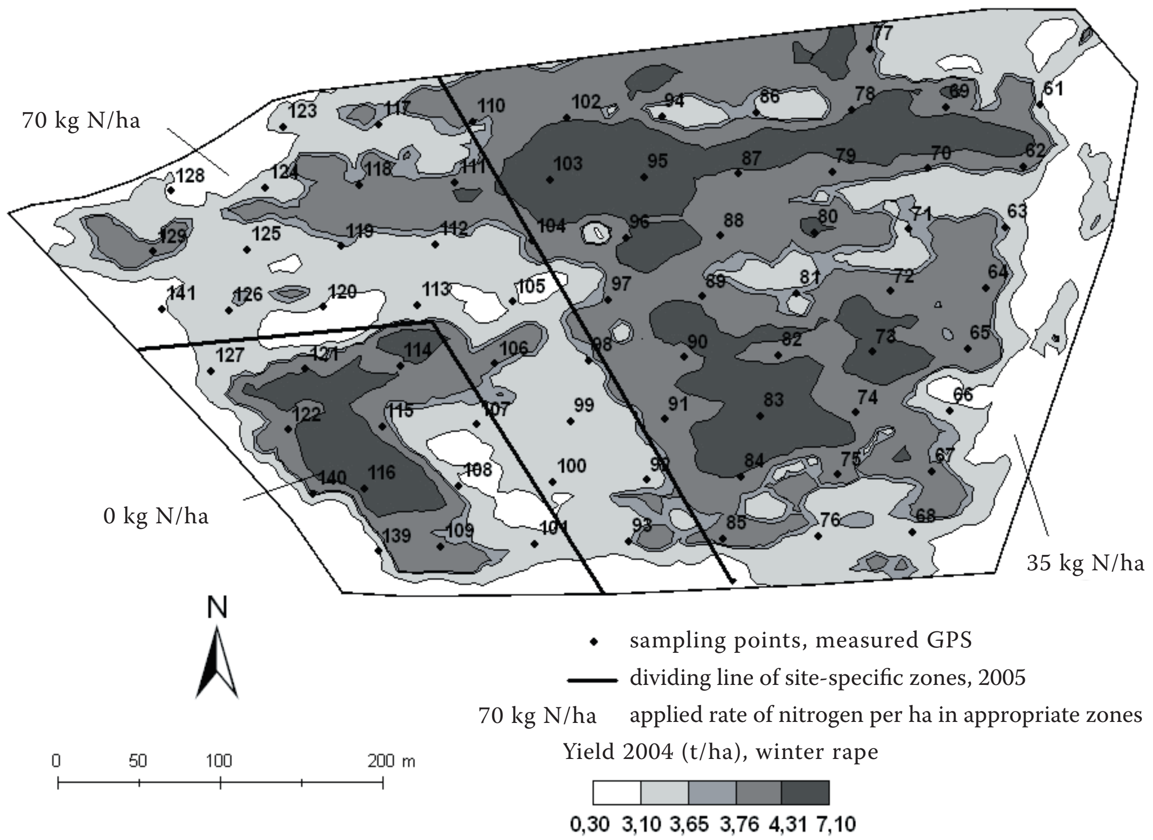

Figure 1. Yield map and the site-specific zones

growing period using the liquid N fertilizer. In the year 2004 the field was divided into two site-specific zones based on NO_3 contents in soil that was measured after harvest in 2003. Into the zone A, where the nitrogen in soil was low, 70 kg of nitrogen per hectare was supplied. Into the zone B with higher content of nitrogen in soil, 35 kg of nitrogen per hectare was supplied. In the following years the field was divided into three zones. In 2005, variable doses of nitrogen fertilizer were determined based on data about nutrient taking by crops (Neuberg 1990). To determine fertilization doses, yield maps of the year 2004 were utilized (Figure 1). In the zones, following nitrogen doses were applied: 35 kg N/ha (zone A), 70 kg N/ha (zone B) and 0 kg N/ha (zone C). In the year 2006 the applied doses of nitrogen were: 57 kg N/ha (zone A), 38 kg N/ha (zone B) and 76 kg N/ha (zone C); the doses were chosen on the basis of the result of yield map from the year 2005. The coloured differentiation of crop yield on the yield map was the same as in the previous year.

In the experimental field a combine harvester equipped with the yield monitor and global position system, that supported creating of the crop yield information layers, carried out the harvest of the cultivated crops since 2003. Measured yield data were processed in the combine harvester onboard computer and together with the position data (longitude, latitude, altitude), they were saved into PCMCIA memory card. The yield and the above-mentioned position data were saved every three seconds. The measured values of yield were corrected at 5% significance level. The data were processed into the yield map with ArcGIS 9.2 statistical software. The created yield maps showed the areas with the crop yield levels and were crucial for management delineation of the experimental field.

Statistica CZ 8.0 programme was used for statistical evaluation of the measured data. The variability of crop yield was expressed by the variation coefficient. Significant differences among average crop yields in zones according to fertilizer rates were evaluated by a method of multiple comparisons with the Tukey significant difference (HSD) test. Yield dependence on soil characteristics, such as pH, P, K, Ca, Mg, C_{org} and N_t, was determined on the basis of multiple regression and forward stepwise correlation.

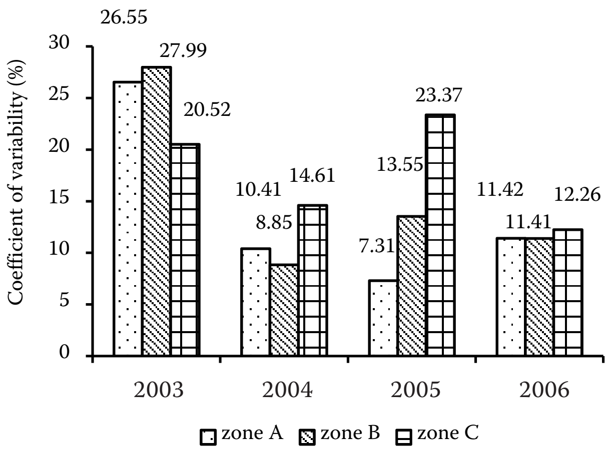

Figure 2. Crop yield variation coefficients in the site-specific zones

RESULTS AND DISCUSSION

Information about the distribution of the crop yield levels and nitrogen contents in soil was an important prerequisite for determination of various doses of N fertilizer in the field. The obtained yield maps after application of variable doses of fertilizer in 2004 to 2006 confirm an increase of areas with higher crop yield in comparison with crop yield in 2003. Areas with lower crop yield were identified on field edges in the year 2004–2006. Lower crop yield could be caused by difficulties of precision applications of fertilizer doses owing to shape of field and maybe by influence of external factors, biotic and abiotic. The crop yield variation coefficients for appropriate zones and years were evaluated (Figure 2). The highest crop yield variability was shown in 2003 at the same dose of fertilizers 146 kg N/ha and average crop yield variability 25.02%. Only the site-specific zone C in 2005 showed the similar crop yield variability as the site-specific zones in 2003. Ground frost reaching –4.6°C on the April 22, 2005 significantly damaged winter wheat plants in boundary parts of site-specific zone C. The zone C is not protected by vegetation cover. In the years 2004–2006, compared to the year 2003, a significant decrease of crop yield variability in appropriate site-specific zones with crop yield variability ranging between 8–14% was confirmed with exception of the above-mentioned zone C in 2005.

Consequently, yield dependence on soil characteristics (pH, contents of P, K, Ca, Mg, C_{org} and N_t in soil) was registered in the experiment. Vaněk et al. (2008) found a largely significant positive correlation between total N content of soil and crop yield in their experimental plot. Our results show that the influence of the above-mentioned soil characteristics on crop yield was more than 40% in 2003, 15% in 2004 and 2005 and 27% in 2006. C_{org} and N_t had a statistical significant influence on crop yield in the case of winter wheat in 2003. The correlation coefficient (r) was $r = 0.50$ for C_{org} and $r = 0.42$ for N_t. The yield of winter rape was influenced by Ca and pH in 2004. The correlation coefficient between winter rape yield and Ca was $r = -0.29$ and between grain yield and pH it was $r = -0.28$. In 2005, K influenced yield of winter wheat significantly with the correlation coefficient $r = -0.24$. C_{org}, N_t and Ca had the most significant influence on oats yield in 2006. The correlation coefficient was $r = 0.43$ for C_{org}, $r = 0.38$ for N_t and $r = 0.31$ for Ca. Based on the results of Montezano et al. (2006) it is not possible to isolate or measure all biotic and abiotic factors that affect the yield in field but knowledge of soil fertility variability and crop yield can contribute to a rationalization of agricultural investments. Authors found a significant and positive linear correlation of organic matter and crop yield. In our experiment a positive correlation coefficient in relation to yield of winter wheat and oats was determined for C_{org} in 2003 and 2006, too. The variability of soil characteristics was identified in all years. The highest variability with the value 45.85% was found for P and 26.41% for K, and the lowest variability with value 2.07% was found for pH and 9.87% for C_{org}. Ca had the average variability 18.21%, Mg 13.65% and N_t had the average variability 7.63% in given years. These values correspond to the results of Brodský et al. (2001), who reported the highest variability in the available P and the second highest variability in the available K. Authors found the lowest variability of all measured soil properties for soil pH.

Dependence among years, site-specific zones and crop yield was evaluated. A significant positive dependence of monitored factors, year 2003 (standard application) and site-specific zones on high level of crop yield variability was found. The conditions of the years 2004, 2005 and 2006 (variable application of N fertilizer on site-specific zones) confirmed a decrease of yield variability coefficient on the experimental field. A significant dependence was determined between the year 2005 and the site-specific zone C. The crop yield variation coefficient in the zone C was higher in comparison with the other zones in the years 2004, 2005 and 2006. The higher crop yield variation coefficient was caused by ground frost in the zone C as it was mentioned above. High nitrogen dose, namely 76 kg N/ha, in combination with the site-specific zone C in 2006 significantly decreased crop yield variability. A similar trend was recorded in the zone A with 57 kg N/ha in 2004. The significant effect of variable rate of nitrogen on crop yield was found in 2003 and in 2005 when winter wheat was cultivated in the experimental field. Average yield of winter wheat was by 0.65 t/ha higher in 2005 in comparison with the average yield of 5.62 t/ha in 2003 at lower supplied dose of nitrogen fertilization (about 35 kg N/ha) on the crop cover. Jorgensen et al. (2007) recorded minor differences in protein content and yield between standard-rate N application and sensor-based variable-rate N application. They used yield and crop quality maps as a basis for field trials with winter wheat treated with four nitrogen applications. Multiple analyses in combination with the Tukey HSD test showed a significant difference in yield between the zones and the years. The most significant differences of yields were among the zones A and C, B and C in the year 2003 and among zones A and C, B and C in the year 2005 (Table 1). The year and variable application of nitrogen fertilizer were not crucial for yield in the zone C (0 kg N/ha) in the year 2005 owing to the influence of abiotic factors. Kumhálová et al. (2008) proved a statistically important positive influence of the N doses (35 and 70 kg N/ha) on crop yield but no influence of flow accumulation on crop yield in the given field in 2005.

In our experiment, it was found that the division of the field into the site-specific zones with characterization of yield level of the cultivated crops and variable application of nitrogen decreased yield variability of the crops in comparison with uniform application of N fertilizer. Higher crop yield and sustainable development was achieved in the experimental field as a consequence of a decrease of nitrogen doses applied on the crop cover.

Table 1. Significant differences of crop yields in the site-specific zones

Year	Zone	Average yield* (t/ha)
2005	C	5.24^{ac}
2003	A	5.42^{a}
2003	B	5.42^{a}
2005	A	6.39^{bc}
2005	B	6.54^{b}
2003	C	6.80^{b}

*the values of average yield with different letter combinations (a, b, c) are significant at $P < 0.05$

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