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# THE EFFECT OF MINERAL FERTILIZATION ON GRAIN YIELD OF MAIZE IN VARIOUS EARLINESS CLASS

# WPŁYW NAWOŻENIA MINERALNEGO NA PLON ZIARNA KUKURYDZY O RÓŻNEJ KLASIE WCZESNOŚCI

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## ABSTRACT

The research aimed to determine the effect of mineral fertilization (NPK) on grain yield of maize in various earliness classes. The field experiment was conducted on very good wheat soil complex (degraded chernozem formed from loess) in the years 2006-2009. The analysed factors were NPK fertilization with 150; 300; 450 kg·ha$^{-1}$ and non-fertilized treatment. The second order factor was three maize cultivars: early Fido c.v., medium early Grom c.v. and medium late –PR38F70. Increase in mineral fertilization (NPK) level influenced a growth of maize grain yield from 8.39 t·ha$^{-1}$ on the non-fertilized treatment to 10.69 t·ha$^{-1}$after the application of the highest fertilizer dose.

**KEY WORDS:** maize, NPK fertilization, cultivars, grain yield, protein

## STRESZCZENIE

Celem badań było określenie wpływu nawożenia mineralnego NPK na wielkość plonu ziarna odmian kukurydzy o różnej klasie wczesności. Doświadczenie polowe prowadzono na glebie kompleksu pszennego bardzo dobrego (czarnoziem zdegradowany wytworzony z lessu) w latach 2006–2009. Badanymi czynnikami były: nawożenie NPK (w kg·ha$^{-1}$): 0, 150; 300; 450). Czynnikiem II rzędu były trzy odmiany kukurydzy (wczesna – 'Fido', średnio wczesna – 'Grom' i średnio późna – 'PR38F70'). Zastosowanie nawożenia mineralnego NPK wpłynęło na zwiększenie plonu ziarna kukurydzy, średnio od 8,39 t·ha$^{-1}$ dla obiektu bez nawożenia, do 10,69 t·ha$^{-1}$ po zastosowaniu najwyższej dawki nawozów.

**SŁOWA KLUCZOWE:** kukurydza, nawożenie NPK, odmiany, plon ziarna, białko

## STRESZCZENIE SZCZEGÓŁOWE

Celem badań było określenie wpływu nawożenia mineralnego NPK na wielkość plonu ziarna odmian kukurydzy o różnych klasach wczesności. Doświadczenie polowe prowadzono na glebie kompleksu pszennego bardzo dobrego (czarnoziem zdegradowany wytworzony z lessu) w latach 2006–2009. Czynnikiem I rzędu było nawożenie NPK w ilości: 0, 150; 300; 450 kg·ha$^{-1}$, a II rzędu - trzy odmiany kukurydzy: wczesna – 'Fido' FAO 210 - 220 , średnio wczesna – 'Grom' FAO 240 i średnio późna – 'PR38F70' FAO 270. Dla obiektu nienawożonego plon ziarna kukurydzy wynosił - w zależności od odmiany - średnio dla lat od 8,07 do 8,79 t·ha$^{-1}$. Po zastosowaniu dawki 150 kg NPK·ha$^{-1}$ plon wzrósł do 9,31-10,34 t·ha$^{-1}$, dawka 300 kg NPK·ha$^{-1}$ wpłynęła na zwiększenie plonu do 9,68-10,82 t·ha$^{-1}$, a dawka 450 kg NPK·ha$^{-1}$ - do 10,04-11,28 t·ha$^{-1}$. Duży wpływ na wielkość plonu ziarna kukurydzy wywierał przebieg pogody. Oddziaływanie to było większe niż wpływ badanych w doświadczeniu czynników. W bardzo suchym roku, jakim był rok 2006, plon ziarna wyniósł średnio 8,54 t·ha$^{-1}$, a w roku 2007, który cechował się wysokimi opadami i temperaturą wyższą od średniej wieloletniej – 11,19 t·ha$^{-1}$. Czynniki doświadczenia nie wpłynęły w sposób istotny na zawartość wody w ziarnie w czasie zbioru, stwierdzono jedynie nieco wyższą wilgotność ziarna u odmian późniejszych. Nawożenie mineralne NPK istotnie kształtowało zawartość białka ogólnego w ziarnie, która dla obiektu kontrolnego wynosiła średnio 87,9 g·kg$^{-1}$ s.m., a dla obiektów nawożonych kolejnymi dawkami - odpowiednio: 94,8, 98,3 i 102,0 g·kg$^{-1}$ s.m. Spośród trzech badanych odmian, najwyższą zawartością białka wyróżniała się odmiana Grom – średnio 102,6 g·kg$^{-1}$ s.m., a najniższą - odmiana PR38F70 – 8,80 g·kg$^{-1}$ s.m.


## INTRODUCTION

One of the most important factors affecting maize grain yield is mineral fertilization. Results of numerous experiments revealed a diversification among cultivars considering their response to mineral fertilization (Cox W.J. Whole 1996, Fotyma 1994, Raun et al., 1995; Szmigiel et al., 2004; Szmigiel et al. 2006). The effectiveness of mineral fertilization depends on the site conditions in which maize is cultivated. Among the site conditions the weather course seriously affects maize grain yield (Jankowiak et al., 1997; Majkowski et al., 1980; Michalski et al. 1996; Oleksy et. al, 2001; Szmigiel et al., 1999; Szmigiel et al., 2004; Tlustos et al. 1997). Maize as a thermopilous plant, does not mature properly in all regions of Poland or each year, whereas high grain water concentrations can make difficult its harvesting using combined harvester. Earlier cultivars, with a shorter vegetation period are able to mature in such conditions, however they produce lower yields. Maize has a low transpiration coefficient, yet while producing large yields it absorbs considerable quantities of water which may be a factor limiting a high grain yield.
Introducing many new maize cultivars makes necessary conducting further research on the influence of mineral fertilization on their yielding in diverse site conditions.

## MATERIAL AND METHODS

The field experiment was conducted in the years 2006-2009 at the Experimental Station of the Crop Production Department AUK in Prusy (N50°07′10″; E20°05′04″, elevation 271 m above sea level) near Krakow on very good wheat soil complex (degraded chernozem developed from loess). The analysed factors comprised three NPK fertilization levels:

1. 60 kg N·ha$^{-1}$, 40 kg $P_2O_5$·ha$^{-1}$, 50 kg $K_2O$·ha$^{-1}$,
2. 120 (90 +30) kg N·ha$^{-1}$, 80 kg $P_2O_5$·ha$^{-1}$, 100 kg $K_2O$·ha$^{-1}$,
3. 180 kg (120+60) N·ha$^{-1}$, 120 kg $P_2O_5$·ha$^{-1}$, 150 kg $K_2O$·ha$^{-1}$,

and control treatment (without fertilization).

The second order factor were three maize cultivars in various earliness class. Cultivar 'Fido' is an early triple hybrid (FAO 210-220). Very good yielding variety. Resistant at fusarium. Moderate lodging resistance. Cultivar 'PR38F70' is a mid late simple hybrid modified (FAO 270). Heavy yield potential. Very good resistance at fusarium and moderate resistance at smut. Large structured hybrid with excellent standing. Cultivar 'Grom' is a mid early simple hybrid modified (FAO 240). Good yielding variety. Tolerantly at diseases and pest. Phosphorus and potassium fertilizers were wholly applied pre-sowing in the form of triple superphosphate (46% $P_2O_5$) and potassium chloride (60% $K_2O$), nitrogen fertilizer (ammonium nitrate 34%) was used pre-sowing and as top dressing. Soil abundance in phosphorus in the years of the studies amounted to 101-138 mg $P_2O_5$·kg$^{-1}$, potassium 112-168 mg $K_2O$·kg$^{-1}$, and magnesium 143-161 mg Mg·kg$^{-1}$. The pH values of the soil determined in 1 mol KCl were 6.2-6.6. Maize, in the amount of 110 thousand kernels per ha, was sown in the last decade of April by means of a point sowing machine on 18m$^2$ plots, in four replications. Each year experiment was planted in a site previously cropped to winter wheat. Weeds control was maintained using Mazine herbicide. Cobs were harvested manually at full grain maturation in the first decade of October.

The moisture content of freshly harvested corn was determined by oven-dried method. The total protein content was determined by Kiejdahl's method (Kjeltec 1028 Analyzer, Tecator; Sweden) the conversion factor applied was 6.25. The results were statistically analysed by variance analysis method using two software programs: AWAR and Statistica 9.0. The lowest significant difference (LSD) for the maize grain yield and other features was computed based on a Tukey's test, at a significance level of $P$ = 0.05.

The weather course during the experiment period was variable (Tables 1 and 2). The year 2006 was dry and warm. Precipitation total for the maize vegetation period that year was lower than the multiannual average by 127 mm, the months of July, September and beginning of October were particularly dry. Average air temperature during maize vegetation period that year was 1.1$^{o}$C higher than average. Year 2007 was very wet, particularly August and September, when rainfall reached 337.7mm compared with 143mm multiannual average. The ain temperature that year was 1$^{o}$C higher. In 2008 precipitation total for maize vegetation period was approximate to average and the air temperature was slightly higher.

Table 1. Distribution of precipitation .
Tabela 1.Rozkład opadów atmosferycznych (w mm)

| Year / Rok | Month - Miesiąc | | | | | | | | Precipitations total / Suma opadów* |
|---|---|---|---|---|---|---|---|---|---|
| | I – III | IV | V | VI | VII | VIII | IX | X | |
| 2006 | 122.0 | 36.3 | 59.6 | 62.0 | 28.0 | 92.6 | 18.3 | 18.2 | 273 |
| 2007 | 166.1 | 15.2 | 56.5 | 58.8 | 71.7 | 124.9 | 212.8 | 78.0 | 552 |
| 2008 | 105.3 | 35.1 | 27.5 | 25.9 | 142.1 | 45.2 | 111.3 | 51.1 | 379 |
| Many years Wielolecie 1977- 2007 | 94.7 | 50.2 | 65.3 | 80.0 | 74.9 | 78.5 | 64.5 | 47.2 | 390 |

*for maize vegetation period/ w okresie wegetacji kukurydzy

Table 2. Distribution of mean air temperatures
Tabela 2.Rozkład średnich temperatur powietrza (º C)

| Rok / Year | Month - Miesiące | | | | | | | | Mean / Średnia |
|---|---|---|---|---|---|---|---|---|---|
| | I - III | IV | V | VI | VII | VIII | IX | X | |
| 2006 | -3.6 | 9.2 | 13.2 | 17.7 | 22.2 | 17.7 | 15.2 | 11.3 | 17.0 |
| 2007 | 3.4 | 10.4 | 15.8 | 18.1 | 19.6 | 19.4 | 13.1 | 8.4 | 16.9 |
| 2008 | 3.3 | 8.6 | 14.1 | 18.5 | 19.1 | 18.2 | 12.8 | 10.7 | 16.2 |
| Many years Wielolecie 1977- 2007 | 0.1 | 8.1 | 13.7 | 16.5 | 18.2 | 17.9 | 13.4 | 8.8 | 15.6 |

## RESULTS AND DISCUSSION

In the conditions of conducted experiments maize grain yield ranged from 7.20 t·ha$^{-1}$ to 12.46 t·ha$^{-1}$, depending on the experimental factors (Table 3). On the control treatment average for three years grain yield was 8.39 t·ha$^{-1}$, NPK fertilization with a dose of 60+40+50 affected increase in yield to 9.76 t·ha$^{-1}$, whereas a successive dose of fertilizers did not cause a proved increase in yield in comparison with the lower dose. The highest NPK dose (160 + 120 + 150) affected increase in yield in relation to the medium dose by 0.56 t·ha$^{-1}$, i.e. to 10.69 t·ha$^{-1}$. Among the three analyzed cultivars, the early Fido c.v. produced the lowest yields, medium early Grom c.v. yielded on a similar level, whereas medium late PR38F70 gave the highest yields. Differences in yields in individual years were higher in comparison with the effect of experimental factors, i.e. fertilization and variety. In 2007 grain yield was the highest, on average 11.19 t·ha$^{-1}$, whereas the lowest yield was obtained in 2008, on average 8.54 t·ha$^{-1}$. Maize grain yield obtained in the experiments, especially on the control treatment (without fertilization) should be regarded as high. On the other hand, fertilization effectiveness was relatively low. A dose of 150 NPK·ha$^{-1}$ caused 16% increase in grain yield and the highest dose 450 kg NPK·ha$^{-1}$ led to 27% increase in relation to the treatment without fertilization. Crop yields produced on very good soil on which the experiment was conducted (very good wheat complex) are generally high, whereas fertilization effectiveness is low (Kruczek 1997; Szmigiel et al., 2004; Szmigiel et al., 2006). A majority of authors researching yielding of maize cultivars in various earliness classes reported that later cultivars with a longer vegetation period yield better, particularly in warmer regions and years (Jankowiak et al., 1997; Kukuła et al., 1978; Oleksy et al., 2001; Szmigiel et al., 2004; Szmigiel et al., 2004). Maize is a crop strongly responding to the weather course. Large grain yield in 2007 should be justified by high precipitations during maize vegetation

period, higher by 162 mm than the multiannual average (Table 1). The year 2007 was a warm year with average air temperature during maize vegetation period 1.3°C higher in comparison with the multiannual average (Table 2). The lowest grain yield gathered in 2006 resulted from very low precipitations, 117 mm lower that the average. Such maize response might have been expected on the basis of previous investigation results presented in the literature (Jankowiak et al., 1997; Michalski et al., 1996; Szmigiel et al., 2004).

None of the experimental factors significantly affected water content in maize grain (Table 4). In both the Authors' (Jankowiak et al., 1997; Michalski et al., 1996; Oleksy et al., 2001; Szmigiel et al., 2004; Szmigiel et al., 2006) and other previous investigations, grain moisture at harvest was a variety-related feature and depended on the weather course.

Table 3. Maize grain yield ($t \cdot ha^{-1}$)
Tabela 3. Plon ziarna kukurydzy ($t \cdot ha^{-1}$)

| Cultivar Odmiana | Year Rok | Fertilization (NPK kg · ha$^{-1}$) - Nawożenie 0 | 150 | 300 | 450 | Mean Średnia |
|---|---|---|---|---|---|---|
| Fido | 2006 | 7.39 | 8.45 | 9.02 | 8.82 | 8.42 |
| | 2007 | 10.38 | 11.34 | 12.20 | 12.46 | 11.60 |
| | 2008 | 7.20 | 8.13 | 8.46 | 8.84 | 8.16 |
| | Mean Średnia | 8.32 | 9.31 | 9.89 | 10.04 | 9.39 |
| Grom | 2006 | 7.31 | 8.18 | 8.50 | 8.70 | 8.17 |
| | 2007 | 8.94 | 11.28 | 11.20 | 12.11 | 10.88 |
| | 2008 | 7.95 | 9.39 | 9.34 | 10.23 | 9.23 |
| | Mean Średnia | 8.07 | 9.62 | 9.68 | 10.35 | 9.43 |
| PR38F70 | 2006 | 7.88 | 8.62 | 8.75 | 9.62 | 8.72 |
| | 2007 | 9.21 | 11.00 | 11.93 | 12.19 | 11.08 |
| | 2008 | 9.28 | 11.41 | 11.77 | 12.04 | 11.12 |
| | Mean Średnia | 8.79 | 10.34 | 10.82 | 11.28 | 10.31 |
| Mean Średnia | 2006 | 7.52 | 8.42 | 8.76 | 9.45 | 8.54 |
| | 2007 | 9.51 | 11.21 | 11.78 | 12.25 | 11.19 |
| | 2008 | 8.14 | 9.64 | 9.86 | 10.37 | 9.50 |
| | Mean Średnia | 8.39 | 9.76 | 10.13 | 10.69 | 9.74 |
| $LSD_{0,05}$-$NIR_{0,05}$ | | | | | | |
| Fertilization Nawożenie | | | | | | 0.405 |
| Cultivars Odmiany | | | | | | 0.315 |
| Years Lata | | | | | | n.i. n.s. |

On control treatments (without fertilizers) protein content in grain was on average 87.9 $g \cdot kg^{-1}$ s.m. (Table 5). NPK fertilization affected an increase in protein content to 94.8, 98.3 and 102.0 $g \cdot kg^{-1}$ s.m., depending on the fertilization level. In PR38F70 c.v. grain protein concentration was the lowest, on average (97.6) 88.0 $g \cdot kg^{-1}$ s.m., while in Grom c.v. it was the highest – 102.6 $g \cdot kg^{-1}$ s.m. In the individual years of the experiment protein content in grain ranged from 95.2 to 96.9 $g \cdot kg^{-1}$ s.m. and the differences were insignificant.

Maize is commonly regarded as energy fodder and contains less protein in comparison with basic cereal grains. However, because of high maize grain yield, protein yield per area unit may equal or even exceed protein yield of forage crops. Protein concentrations in the Authors' own research were higher than the values

reported in literature, which was due to cultivation in a very good soil. The fact has been confirmed by the Authors' previous experiments conducted on this soil (Szmigiel et al. 1999; 2004; 2006).

Table 4. Water content in maize grain at harvest (g $kg^{-1}$ of d.m.))
Tabela 4. Zawartość wody w ziarnie kukurydzy podczas zbioru (g $kg^{-1}$ s.m.)

| Fertilization NPK kg·ha$^{-1}$ Nawożenie | Varietes - Odmiany | | | Year - Lata | | | Mean Średnia |
|---|---|---|---|---|---|---|---|
| | Fido | Grom | PR38F70 | 2006 | 2007 | 2008 | |
| 0 | 245 | 254 | 264 | 278 | 240 | 246 | 254 |
| 150 | 245 | 259 | 268 | 274 | 241 | 258 | 258 |
| 300 | 244 | 263 | 264 | 282 | 235 | 253 | 257 |
| 450 | 248 | 260 | 274 | 281 | 246 | 257 | 261 |
| Mean Średnia | **246** | **259** | **268** | **279** | **240** | **254** | |

$LSD_{0.05}$-$NIR_{0.05}$
Fertilization – n.i. n.s., Cultivars - n.i. n.s. Years - n.i. n.s.

Table 5. Protein content in maize grain (g $kg^{-1}$ of d.m.)
Tabela 5. Zawartość białka w ziarnie kukurydzy (g $kg^{-1}$ s.m.)

| Cultivar Odmiana | Year Rok | Fertilization - Nawożenie | | | | Mean Średnia |
|---|---|---|---|---|---|---|
| | | 0 | 150 | 300 | 450 | |
| Fido | 2006 | 80.2 | 91.9 | 101.4 | 107.8 | 95.4 |
| | 2007 | 82.0 | 99.1 | 108.9 | 111.4 | 100.4 |
| | 2008 | 94.7 | 98.2 | 96.4 | 98.4 | 96.9 |
| | Mean | **85.6** | **96.4** | **102.2** | **105.9** | **97.6** |
| Grom | 2006 | 96.0 | 100.7 | 105.6 | 108.4 | 102.7 |
| | 2007 | 91.1 | 98.3 | 101.3 | 103.2 | 98.5 |
| | 2008 | 103.2 | 107.8 | 103.7 | 111.6 | 106.6 |
| | Mean | **96.8** | **102.3** | **103.5** | **107.7** | **102.6** |
| PR38F70 | 2006 | 78.8 | 86.4 | 90.4 | 93.8 | 87.4 |
| | 2007 | 87.6 | 89.2 | 93.7 | 96.4 | 91.7 |
| | 2008 | 77.6 | 81.9 | 83.1 | 86.9 | 84.9 |
| | Mean | **81.3** | **85.8** | **89.1** | **92.4** | **88.0** |
| Mean Średnia | 2006 | 85.0 | 93.0 | 99.1 | 103.3 | 95.2 |
| | 2007 | 86.9 | 95.5 | 101.3 | 103.7 | 96.9 |
| | 2008 | 91.8 | 96.0 | 94.4 | 99.0 | 96.1 |
| | Mean | **87.9** | **94.8** | **98.3** | **102.0** | **96.1** |

$LSD_{0.05}$-$NIR_{0.05}$
Fertilization - 4.05 , Cultivars - 3.15, Years - n.i. n.s.

## CONCLUSIONS

1. Increase in mineral fertilization (NPK) affected a larger maize grain yield from 8.39 t·$ha^{-1}$, to 10.69 t·$ha^{-1}$.
2. Among the three analyzed cultivars, PR38F70 produced the highest yields – on average 10.31 t·$ha^{-1}$, whereas Fido gave the lowest yield – on average 9.39 t·$ha^{-1}$.
3. The weather course had a considerable influence on maize grain yield. In a very dry year average grain yield was 8.54 t·$ha^{-1}$, while in a very wet year 11.19 t·$ha^{-1}$.
4. Mineral fertilization (NPK) affected an increase in grain protein content from 87.9 g·$kg^{-1}$ s.m. on the treatments without fertilization to 102.0 g·$kg^{-1}$ s.m. after the application of the highest fertilization level. The highest amount (102,6 g·$kg^{-1}$ s.m.)

of protein was content in Grom cv. grain and the lowest (88,0 $g \cdot kg^{-1}$ s.m.) in PR38F70 grain.

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