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Effect of zinc application timing on yield formation by two types of maize cultivars

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ABSTRACT

The yield forming response of maize cultivar to zinc (Zn) application depends on its timing. This hypothesis was validated in 2007, 2008, 2009 and 2010 growing seasons. The zinc treatments as the first factor were: NPK; NPK + Zn applied before sowing; NPK + Zn applied to maize at the stage of 4th leaf. The second factor was the maize type: stay-green (modern cultivars) – Paroli, Veritis, Anamur; classical (old cultivars) – Inagua, Kirola. The grain yield of modern cultivars responded the best to zinc applied before sowing, whereas the old ones, when applied to foliage. The yield of the stay-green maize depended upon the number of kernels per row, whereas the classical one on all yield structural components. The zinc management in the modern cultivars should be oriented towards maximization of the number of kernels per row, whereas in the old one on its optimization with the simultaneous kernel weight increase. The positive impact of zinc application before sowing on dry matter translocation from vegetative tissues to growing kernels underlines its practical usefulness, especially in areas with frequent water shortage during maize growth.

Keywords: *Zea mays* L.; micronutrient; crop biomass; dry matter partitioning and remobilization; yield structure

In recent years, a huge world-wide increase in maize-sown has been observed. In the period 2004–2013, the yearly global growth rate reached 3.58%, but the yield progress was below 1% (FAOSTAT 2015). These two characteristics indicate that the yield potential of maize is not fully exploited. One of the key reasons of a slow yield increase is insufficient zinc supply to plants during critical stages of growth. The shortage of zinc supply is recorded in most countries, where maize is a dominant crop (Khoshgoftarmanesh et al. 2010).

Yield formation by maize depends on zinc supply to plants during critical periods, which are decisive for the number of kernels per plant (NKP) set up and their weight (TKW). The first yield component develops during the period extending from germination and ending at the blister stage of the kernel growth. The second period, termed as the grain filling, begins with early milk stage and affects the kernel weight (Potarzycki 2010). The important sources of assimilates for the growing grain in the classical maize cultivars, are current photosynthesis and dry matter resources in vegetative organs. Modern maize cultivars differ significantly in the grain filling strategy. They show photosynthetic activity up to maturity. This growth strategy is a result of the prolonged activity of leaves and roots (Rajcan and Tollenaar 1999, Szulc et al. 2012). Maize is a crop sensitive to zinc supply as indicated by its high content in grain, as compared to other micronutrients (Lošák et al. 2011, Maňásek et al. 2013). This fact can be explained by zinc importance for performance of yield components in maize. This period extends from the early stages of growth up to final maturity (Grzebisz et al. 2008).

The key objective of this paper is to determine the sensitivity of five maize cultivars, representing classic and modern stay-green types to zinc application timing and its effect on the degree of yield component's performance. The minor objective is to explain differences in maize types based on the degree of dry matter remobilization during grain filling.

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MATERIAL AND METHODS

The field experiment was established at Bierzglinek (52'30°N, 17'58°E, Poland) on soil originated from loamy sand, classified as Albic Luvisol. Content of humus was low (1%). Content of available nutrients, measured each year before application of fertilizers, was in the medium class: (i) phosphorus: 57–59 mg P kg/soil; (ii) potassium: 91–98 mg K kg/soil (double lactate – Egner Riehm method); (iii) zinc: 5–6 mg Zn kg/soil (1 mol/L HCl, Rinkis method), and mineral nitrogen (N_{min}): 40–61 kg/ha (0.01 mol/L $CaCl_2$). Soil pH was around 6.0 (1 mol/L KCl). Phosphorus (single superphosphate, 23 kg P/ha) and potassium as Korn-Kali (73 kg K/ha) was applied prior to sowing. Nitrogen, as ammonium nitrate, was applied in rates of 120–130 kg N/ha. Zinc as zinc ammonium acetate was applied in the rate of 1.5 Zn kg/ha. The field trial was arranged as a two-factorial split-block design, replicated three times:

Zinc application timing: NPK – control (NPK_c), before sowing (NPK_{bs}), to maize foliage at the stage of 4th leaf (NPK_f);

Maize types/cultivars: stay-green (modern) – Paroli (P), Veritis (V), Anamur (A); classical (old) – Inagua (I), Kirola (K).

Maize was sown in the mid of April at density of nine plants per m^2. At maturity, plants were harvested from the area of 24 m^2 by a plot combine harvester. Yield was adjusted to the 86% of dry matter content. Yield structural components were determined using 16 cobs, randomly chosen. Harvest and dry matter remobilization indices were calculated based on formulas:

Cob harvest index (HI_C, %):

$$HI_C = CY/TBH \times 100,$$

Grain harvest index (HI_G, %):

$$HI_G = GY/TBH \times 100,$$

Biomass remobilization to cob (BRtC, g/m^2):

$$BRtC = TBF - BVO,$$

Coefficient of dry matter remobilization (%):

$$FRtC = BRtC/TBF \times 100,$$

Where: CY – yield of cobs (g/m^2); GY – yield of grain (g/m^2); TBH – total biomass at harvest (g/m^2); TBF – total maize biomass at the mid-flowering (g/m^2); BVO – biomass of vegetative maize organs at harvest (g/m^2).

The data obtained experimentally were subjected to the analysis of variance (Statistica 10) software (StatSoft, Inc., Tulsa, USA). Differences between the treatments were evaluated with the Tukey's test. Results of the *F*-test (***, **, *) that indicate significance at the $P \leq 0.1$, 1, and 5%, respectively) are given in tables and figures. The path diagram was constructed to assess the impact of yield components treated as independent variables on yield as the dependent variable. The choice of the key predictor is based on the highest value of the correlation coefficient for each set of variables. The developed regression models rely on the computing procedure, in which a consecutive variable is removed from the multiple linear regressions in the step-by-step manner (Konys and Wisniewski 1984).

RESULTS AND DISCUSSION

Maize biomass and grain yield at harvest. The course of weather during the study was the key factor that affected seven of nine maize characteristics at harvest (Table 1). The plant biomass drop recorded in 2008 was due to shortage of precipitation during summer (Figure 1). The most positive impact of zinc on yield revealed, when applied to maize foliage (NPK_f). The grain yield gain was 11% and 19% compared to NPK_{bs} and NPK_c plots, respectively. This fact corroborates the observation by Potarzycki and Grzebisz (2009), Fecenko and Ložek (1998), and recently by Asif et al. (2013). Cob covering leaves (+16%), and cob core (+12% and +18%, respectively) showed the same pattern of response to zinc application timing. As a result, harvest indices of cobs and grain were higher in treatments with zinc. It is in agreement with the data reported by Drissi et al. (2015).

The recorded sensitivity of maize cultivars to zinc is probably due to different genetic traits (Simic et al. 2009). The yield of maize, averaged over each group of cultivars, was significantly modified by zinc timing (Figure 2). The yield of stay-green cultivars increased due to zinc application by 18%. In classical ones, it depended on zinc timing. Yield increase due to zinc application at the stage of 4th leaf was by 19% (+1.65 t/ha) but before sowing by 7% (+0.58 t/ha) higher as compared to the NPK.

Components of yield structure. The weather course was the decisive factor impacting variability of yield components (Table 2). The number of rows per cob (NRC) was cultivar specific. The

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Table 1. Characteristics of maize biomass and its partitioning among organs at maturity

Experimental factor		Stem	Leaves	Grain	Cob covering leaves	Cob core	Total	Grain index	Cob index
		(t DM/ha)						(%)	
Year (A)	2007	5.03	3.25	9.84	0.92	1.66	20.7	47.6	60.1
	2008	3.34	2.15	7.77	0.73	1.21	15.2	51.0	63.8
	2009	4.33	2.35	10.40	0.72	1.52	19.3	53.9	65.5
	2010	5.31	2.46	10.44	0.89	1.67	20.8	50.3	62.6
$LSD_{0.05}$		0.19**	0.13**	0.26**	0.08**	0.09**	0.49**	1.0**	1.0**
Zinc fertilization (B)	NPK	4.58	2.56	8.73	0.78	1.41	18.1	48.7	60.8
	NPK + Zn_{bs}	4.42	2.49	9.69	0.77	1.48	18.9	51.5	63.5
	NPK + Zn_f	4.50	2.61	10.41	0.90	1.66	20.1	51.9	64.6
$LSD_{0.05}$		ns	ns	0.23**	0.07**	0.08**	0.43**	0.8**	0.9**
Cultivar (C)	Paroli	4.67	2.42	9.76	0.87	1.45	19.2	51.0	63.1
	Veritis	4.55	2.53	9.46	0.76	1.58	18.9	50.2	62.6
	Anamur	4.57	2.75	9.49	0.83	1.56	19.2	49.6	61.9
	Inagua	4.49	2.58	9.70	0.84	1.47	19.1	51.0	63.1
	Kirola	4.23	2.50	9.64	0.78	1.51	18.7	51.9	64.2
$LSD_{0.05}$		0.21**	0.15**	ns	ns	0.10*	ns	1.1**	1.1*
Interaction	A × B	**	**	**	ns	**	**	**	**
	A × C	*	**	**	ns	ns	**	**	**
	B × C	**	ns	**	ns	**	**	ns	*
	A × B × C	**	**	**	ns	ns	**	*	**
CV (%)		19.3	18.9	12.7	18.7	14.6	13.2	5.3	4.3

*$P < 0.05$; **$P < 0.01$; ns – not significant; *LSD* – least significant difference; *CV* – coefficient of variation; Zn_{bs} – NPK + Zn before sowing; Zn_f – NPK + Zn foliage applied

ascending order of cultivars: P < V ≤ A ≤ I ≤ K stresses stronger resistance of classical cultivars to variability of weather. The number of kernels per row (NKR), showed a significant sensitivity to all studied factors. A comparative analysis of both yield components in 2007 and 2008 indicates that

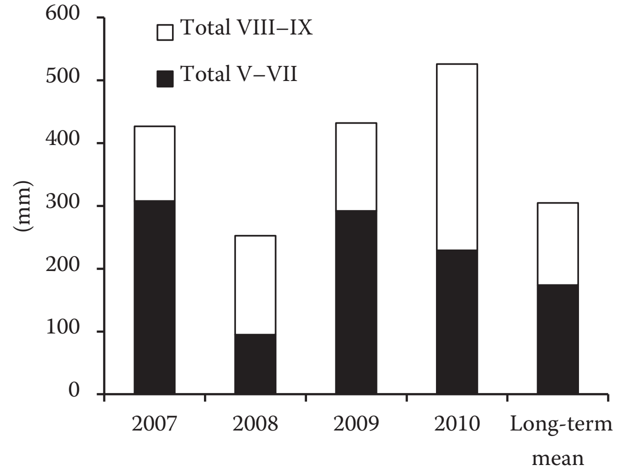

Figure 1. Rainfall amount and distribution during the growing season

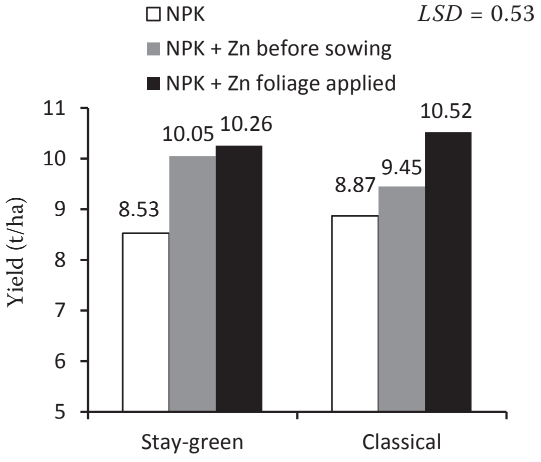

Figure 2. Grain yield response to interaction of cultivar type and zinc timing

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Table 2. Characteristics of yield forming components

Experimental factor		Number of rows per cob	Number of kernels in the row	Number of kernels per cob	Thousand kernels weight (g)
Year (A)	2007	13.9	33.1	460	330
	2008	14.7	26.4	390	301
	2009	14.6	28.7	421	322
	2010	14.8	29.1	420	316
$LSD_{0.05}$		0.3^{**}	0.9^{**}	17^{**}	6^{**}
Zinc fertilization (B)	NPK	14.5	26.9	390	310
	NPK + Zn_{bs}	14.4	29.3	420	320
	NPK + Zn_{f}	14.7	31.2	458	322
$LSD_{0.05}$		ns	0.8^{**}	15^{**}	6^{**}
Cultivar (C)	Paroli	13.3	29.4	392	346
	Veritis	14.4	28.4	408	322
	Anamur	14.7	28.6	420	317
	Inagua	15.3	29.2	445	302
	Kirola	15.0	29.1	449	300
$LSD_{0.05}$		0.4^{**}	0.9^{*}	19^{**}	7
Interaction	A × B	**	**	**	**
	A × C	ns	ns	ns	**
	B × C	ns	**	*	ns
	A × B × C	ns	**	ns	*
CV (%)		3.8	9.7	8.2	5.3

$^{*}P < 0.05$; $^{**}P < 0.01$; ns – not significant; *LSD* – least significant difference; *CV* – coefficient of variation; Zn_{bs} – NPK + Zn before sowing; Zn_{f} – NPK + Zn foliage applied

the number of kernels per cob (NKC) followed the NKR pattern (Figure 3). In the stay-green group, the applied zinc, irrespectively on its timing, increased the NKR by 15%. In the classical one, a significant impact of zinc on this characteristic was recorded, provided its application to foliage. The thousand kernel weight (TKW) was performed by all factors.

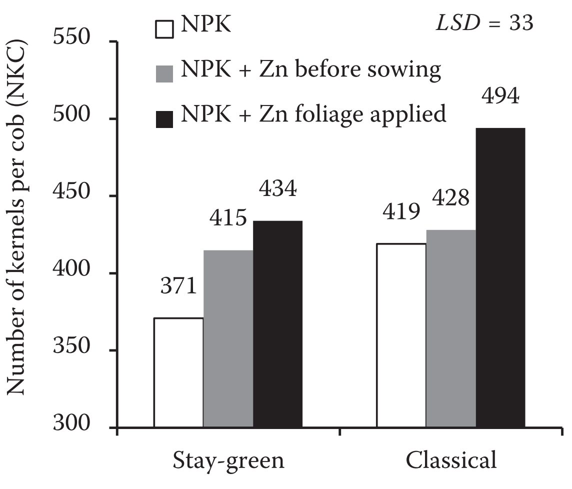

Figure 3. Number of kernels per cob as affected by interaction of cultivar type and zinc timing

The yield of grain and its primary components, i.e. NKR and TKW, showed a significant response to interaction of the experimental factors and years (Tables 1 and 2). In order to explain these variabilities, a stepwise regression was applied, treating yield of grain as a dependent variable and yield components as independent variables. The coefficient of determination (R^2) was used as the key criterion for the model validation. In the stay-green group, the NKR revealed as the single yield variable. In the classical group, the yield of grain was predicted by all components included within the model. The statistical correctness of both models is corroborated by values of the mean square error, which reached the lowest values

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Table 3. Multiple regression analysis with the choice of the best subset of independent variables (yield components) versus dependent variable (yield) (mean for 2007–2010)

Cultivar type	Number of independent variables	Coefficient of determination (R^2)	Mean square error	Best subset of independent variables		
Stay-green: Paroli, Veritis, Anamur	3	54	0.89	NRC	NKR	TKW
	2	53	0.88	NRC	NKR	
	1	50	0.87		NKR	
Classical: Inagua, Kirola	3	64	1.00	NRC	NKR	TKW
	2	55	1.21		NKR	TKW
	1	39	1.58		NKR	

NRC – number of rows per cob; NKR – number of kernels per cob; TKW – thousand kernel weight

of 0.87 and 1.00 for the first and second group, respectively (Table 3). The direct and indirect effect of yield components on yield of grain was assessed by a path analysis. As shown in Figure 4, compensatory response of yield components was poor or negligible. In both groups of cultivars, the key yield predictor was the NKR. In the stay-green group, it was negatively impacted by the number of rows per cob. For the classical one, the NKR exerted a positive impact on TKW. This dependence indicates on the lack of negative impact of the number of kernels per cob on their weight during the grain filling period.

Remobilization of dry matter during the grain filling period. The key reason of biomass year-to-year variability at the mid-flowering was water shortage in early stages of maize growth in 2008 (Table 4, Figure 1). This factor disturbed a performance of yield components. The decrease in the number of kernels per row can be explained by abortion of seed initials (Boyer and Westgate 2004). The rate of biomass accumulation during the vegetative part of maize growth depends on nitrogen supply. This process, to some extent, is controlled by zinc (Grzebisz et al. 2008). Plants fertilized with zinc applied before sowing, produced more biomass at the mid-flowering (B_f) compared with the NPK ones. The NKR relation to maize biomass was described by the quadrate regression model:

$$NKR = -0.227B_f^2 + 6.569B_f - 14.42 \text{ for } n = 60,$$
$$R^2 = 0.67, \text{ and } B_{f\,optimum} = 14.51 \text{ t/ha}.$$

As a rule, zinc application resulted in higher B_f, in turn increasing the NKR. The exception was the wet year 2007 when the applied zinc led to B_f decrease, in turn increasing the number of kernels per row. This phenomenon can be explained by the increase in indole-3-acetic-acid and endogenic gibberellin concentration in plant roots fertilized with zinc (Barker and Eaton 2015). This process impacts the rate of nitrogen uptake by plants,

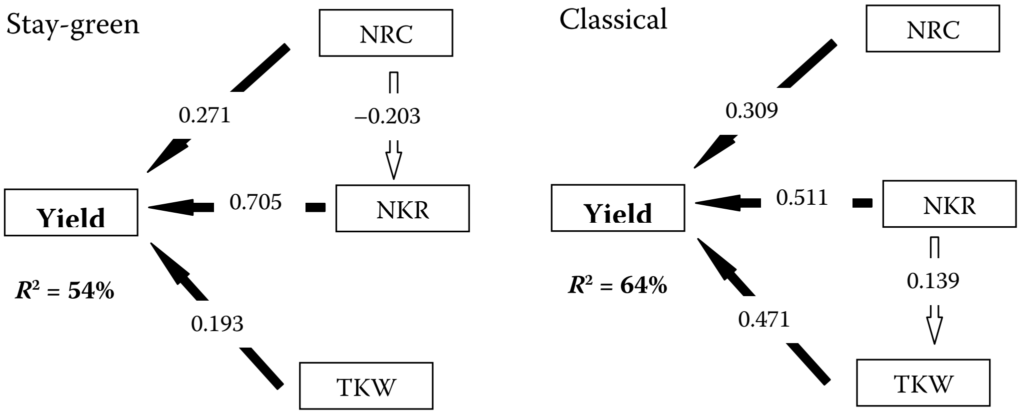

Figure 4. Paths coefficients between yield and yield components. NRC – number of rows per cob; NKR – number of kernels per cob; TKW – thousand kernel weight

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Table 4. Maize biomass at flowering stage (65 BBCH) and its remobilization to cob (BRtC) after flowering

Experimental factor		Biomass (t DM/ha)	BRtC (g/m^2)	FRtC (%)
Year (A)	2007	13.48	143	11.5
	2008	8.99	224	23.8
	2009	10.50	193	15.1
	2010	10.30	161	12.4
LSD$_{0.05}$		0.14**	22**	2.1**
Zinc fertilization (B)	NPK	10.28	122	11.7
	NPK + Zn$_{bs}$	11.23	229	20.6
	NPK + Zn$_f$	10.95	189	14.8
LSD$_{0.05}$		0.12**	19**	1.8**
Cultivar (C)	Paroli	10.64	163	13.7
	Veritis	10.33	140	12.2
	Anamur	11.33	194	17.4
	Inagua	11.11	200	17.5
	Kirola	10.82	201	17.8
LSD$_{0.05}$		0.16**	25**	2.3**
Interactions	A × B	**	**	**
	A × C	**	**	**
	B × C	**	**	**
	A × B × C	**	**	**

*$P < 0.05$; **$P < 0.01$; ns – not significant; DM – dry matter; FRtC – coefficient of dry matter remobilization; *LSD* – least significant difference; *CV* – coefficient of variation; Zn$_{bs}$ – NPK + Zn before sowing; Zn$_f$ – NPK + Zn foliage applied

in turn accelerating the rate of biomass growth and increase in the number of kernels per plant (Potarzycki 2010).

One of the key mechanisms driving the yield of grain is the amount of dry matter mobilized after flowering from vegetative tissues and subsequently transferred into growing grains. This process is important, especially under conditions of water stress during grain filling (Rajcan and Tollenaar 1999). This phenomenon was observed in 2008, a year with drought in summer. The analysis of Figure 5 implicitly stresses the importance of interaction between zinc timing and maize type on the amount of dry matter remobilization during the post-flowering growth of plants. Those, which were fertilized with zinc before sowing achieved a considerably higher value of the BRtC index, irrespectively on the chosen cultivar. The lower values were recorded for the stay-green cultivars. This discrepancy can be explained by prolonged photosynthetic activity of modern cultivars, effectively taking up water and minerals during grain filling (Szulc et al. 2012).

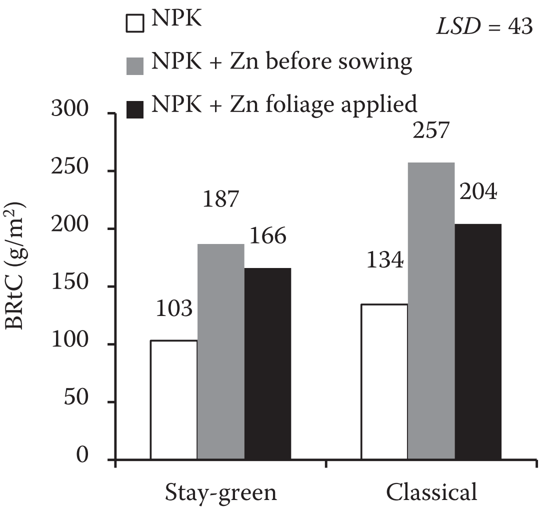

Figure 5. The amount of dry matter remobilization to cobs after flowering as affected by interaction of cultivar type and zinc timing. BRtC – biomass remobilization to cob

It can be concluded that zinc application to maize is a factor affecting positively its yielding potential. The yield forming effect of this nutrient prevailed in early stages of maize growth, resulting in a higher number of kernels per cob. In the classical group of cultivars, yield of grain depended also upon the rate of dry matter remobilization during the grain filling period. The response of old type cultivars to zinc applied to foliage can be explained by its positive impact on carbonic anhydrase activity, which prolongs photosynthetic activity of leaves (Guliev et al. 1992). Consequently, the grain filling period undergoes extension, resulting in thousand kernel weight increase. An efficient management of maize, under rain-fed conditions, should take into account the specific response of the sown cultivar to zinc timing. In areas with frequent drought, the pre-sowing zinc application ameliorates yield losses, through the increased quotas of dry matter remobilization from vegetative parts of maize and its effective allocation in kernels.

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