Effect of magnesium or zinc supplementation at the background of nitrogen rate on nitrogen management by maize canopy cultivated in monoculture

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ABSTRACT

In five consecutive growth seasons from 2003 to 2007 a response of maize variety Eurostar (var. FAO 240) to supply of NPK fertilizer supplemented with magnesium or zinc was investigated. The aim of the study was to evaluate the role of zinc (NPK + Zn) or magnesium (NPK + Mg) in controlling nitrogen management by maize crop fertilized with 80 and 140 kg N/ha. In the course of the study, total grain nitrogen content did not show any response to both experimental factors and weather variability, as well. However, the obtained results indicate, that magnesium and zinc have significantly increased SPAD (chlorophyll index) indices of maize cob leaf at anthesis. A significant effect of both factors interaction on nitrogen accumulation in grain and cob covering leaves was noted, but limited to the 80 kg N/ha treatment. The physiological role of Mg and Zn in nitrogen management was most manifested throughout its greater recovery from nitrogen fertilizer applied at the rate 80 kg N/ha, amounting to 92 and 94% respectively; for the NPK, it was only 78%.

Keywords: fertilizer's additives; SPAD index; indices

Maize is a crop characterized by a particular dynamic pattern in the formation of basic element of yield structure and hence it is very sensitive to the supply of nutrients in early stages of growth, nitrogen specially (Fageria and Baligar 2005, Subedi and Ma 2005, Grzebisz et al. 2008). With respect to the yield forming role of nitrogen on one hand as well as the environmental threat related to active nitrogen dispersion on the other hand, trials over nitrogen efficiency in maize cropping are acquiring prime importance (Schröder et al. 1998, Montemurro et al. 2006). The recovery of nitrogen from fertilizers is related to the rate of its uptake in vegetative as well as during grain filling period of maize growth. Nitrogen internal efficiency however does not only depend on its total amount taken up by the crop, but also on the concomitant supply of secondary nutrients (Rasheed et al. 2004), magnesium mainly (Jones and Huber 2007) and micronutrients of which zinc is the most important (De Souza et al. 1998, Potarzycki and Grzebisz 2009).

Nitrogen metabolism is strictly related to the presence of magnesium in the chlorophyll and its role as a cofactor of the activity of enzymes responsible for the remobilization and transportation of metabolites (nitrogen among others) from the vegetative plant parts to the developing kernels. Moreover since magnesium activates a large number of enzymes in the plant, its simultaneous supply increases the rate of mineral nitrogen transformation into proteins (Pessarakli 2002).

Zinc plays an important role in maize yield building-up (De Souza et al. 1998), and can control nitrogen management of this plant. Data reported by Grzebisz et al. (2008) showed, that the increase in nitrogen uptake rate by plant canopy at two distant growth stages, i.e., from 7th to 9th leaf stage and from milk to physiological maturity of grain, considered as secondary effect, was induced by zinc application at early stage of maize growth. According to Potarzycki and Grzebisz (2009), foliar application of zinc at the 5th leaf stage can increase the partial factor of fertilizer nitrogen productivity (PFPN) as compared to the classical NPK fertilization.

The aim the current paper was to evaluate nitrogen management by maize crop grown in monoculture and assess the efficiency of nitrogen fertilizer under conditions of maize crop growth as imposed by application of NPK fertilizer supplemented with magnesium or zinc.

MATERIALS AND METHODS

Field trials were carried out for five consecutive years, from 2003 to 2007 at an agricultural farm located in Nowa Wieś Królewska (52.26°N, 17.57°E, Poland). The static field-trial was established on an albic luvisol soil originated from a postglacial loamy sediments. The soil under study in 2003, i.e. at the beginning of the experiment set-up, was generally suitable for maize cultivation, as results from analysis of basic soil agro-chemical features presented in the Table 1. Content of mineral nitrogen at the beginning of each growing season was generally in a very narrow range, from 53 to 69 kg N/ha, creating a good start for the maize crop growth (Table 1).

Amounts of precipitation received by maize crop during each growing season were variable, fluctuating from 181 mm in 2003 to 427 mm in 2007. The bad growing conditions, considering only amount of precipitation in July, occurred in 2006 and 2003 (Table 2).

Maize, variety Eurostar (FAO 240), was cropped in progressing monoculture for five consecutive years. A two-factorial field trial, replicated four times was established in a block system design with the following factors:
nitrogen rate: (a) 80 kg N/ha, (b) 140 kg N/ha;
NPK fertilizer:
NPK supplemented with zinc [NPK + Zn];
NPK supplemented with magnesium [NPK + Mg];
NPK [NPK].

In order to determine main parameters of nitrogen fertilizer efficiency an additional treatment without nitrogen (absolute control) was set-up to the above described trial's schema.

Amounts of basic fertilizers applied annually were as follows: (a) phosphorus – 26.4 kg P/ha (b) potassium – 99.6 kg K/ha. Amount of zinc and magnesium applied as supplement to the NPK fertilizer based on super phosphate was 1.5 kg Zn/ha (in the form of zinc sulphate) or 15 kg Mg/ha (in the form of magnesium carbonate). All fertilizers were applied two weeks before maize sowing, which took place in the third decade of April in all years.

The yield of grain and vegetative biomass was determined from an area of 24 m^2 (two central rows of 16 m length) in four replications. Nitrogen content in plant parts (stem, leaves, covering leaves, cob core, kernels) was determined by the Kjeldahl method. The SPAD index was measured at anthesis (BBCH 65) by using the Yara N-tester. Nitrogen uptake by maize crop was calculated as a result of aboveground biomass of maize crop times nitrogen content in the given plant part. The nitrogen harvest index (NHI) reported in the current work represents a percentage share of nitrogen uptake by grains within its total uptake (TU) by the aboveground plant biomass. Next parameter, nitrogen recovery (N_{rec}) of applied fertilizers, was calculated as follows:

$$N_{rec}\ (\%) = (N_f - N_c) \times 100/D$$

Where: N_f – nitrogen uptake by fertilized plants (kg/ha); N_c – nitrogen uptake by plants in the control (unfertilized plot) (kg/ha); D – nitrogen rate (kg/ha).

The results were subjected to the analysis of variance, and the differences were evaluated with the Tukey's test.

RESULTS AND DISCUSSION

Maize yielding potential is closely related to nitrogen management during the whole vegetative growth period (Hermann and Taube 2005, Montemurro et al. 2006). At the anthesis stage both mineral additives of the NPK fertilizer, referred to magnesium and zinc, significantly influenced values of the SPAD index (Table 3). In addition,

Table 1. Agrochemical properties of arable soil, years 2003–2007 (layer 0–30 cm)

Statistical characteritics	Soil reaction 1 mol/dm^3 KCl	Organic carbon[a] (g/kg)	Available phosphorus[b] (mg P/kg)	Available potassium[b] (mg K/kg)	Available magnesium[c] (mg Mg/kg)	Available zinc[d] (mg Zn/kg)	Mineral nitrogen (kg N/ha)[e] (layer 0.00–0.60 m)
Range	5.6–5.9	18.9–19.4	55.2–61.0	116.2–128.7	47.5–55.0	5.8–6.1	59.0–69.0
Mean (x ± SD)	5.8 ± 0.11	19.1 ± 0.19	57.9 ± 2.93	122.0 ± 7.74	51.0 ± 2.85	6.0 ± 0.13	62.4 ± 6.62
CV (%)	1.98	1.02	5.05	3.88	5.59	2.18	10.61

[a]Tiurin method; [b]Egner-Riehm method; [c]Schachtschabel method; [d]1 mol/dm^3 HCl; [e]0.01 mol/dm^3 $CaCl_2$

Table 2. Distribution of precipitation during each growing season (mm), years 2003–2007

Month	2003	2004	2005	2006	2007	Long-term mean 1960–2002
May	24.5	41.9	97.3	66.6	81.6	44
June	23.7	42.8	25.4	37.6	81.4	56
July	80.2	35	73.5	7.2	145	74
August	13.5	61.9	52.8	176.6	65.4	54
September	11.7	22.2	22.4	34.4	32.4	45
October	27.8	52.2	5.7	35	21	32
Total	181	256	267	357	427	305

the variability of nitrogen content in the maize leaf located just below the cob explains sufficiently well the variation of SPAD indices (Figure 1). Therefore the SPAD test may be applied as a reliable method for diagnosing nitrogen status of maize crop at anthesis. These relationships indirectly stress the significance of both nutrients in controlling leaf photosynthetic activity and explain the importance of this plant part as a starch donor for developing grains (Rajcan and Tollenaar 1999). While the data obtained in treatments NPK + Mg can be related to the presence of Mg in the chlorophyll molecule, in those outlined from NPK + Zn, the effect of zinc on the extended length of the period of carbohydrates synthesis by leaves was reported by Gibson and Leece (1981) and Guliev et al. (1992).

Total nitrogen content (TNC) in maize plant parts at its physiological maturity showed the year-to-year variability, with the lowest coefficient of variation (*CV*) attributed to kernels and cob cores. The highest *CV* was however found for stems and cob covering leaves (Table 4). Among the studied maize organs, leaves and cob covering leaves significantly responded to the applied N rate. The effect of mineral additives of the NPK fertilizer was, except the cob core, insignificant (Table 5). Total nitrogen content in kernels did not show any response to both applied experimental factors. In the light of presented data this maize part can be therefore considered as conservative plant organ in this respect. In some scientific papers the observed phenomenon is explained by variety-specific response to applied N, based on its genetically established background (Duarte at al. 2005). This idea is supported by Pommel et al. (2006) who formulated a thesis, that processes of assimilates partitioning among maize parts are governed by a set of genes. However, this phenomenon can be also explained by means of prolonged capacity of stay-green varieties to accumulate starch during final stages of plant maturation, whereas nitrogen accumulation stops much earlier, i.e. at dough stage of grain development (Ma and Dwyer 1998, Herrmann and Taube 2004). Hence, this phenomenon presents a classical nitrogen dilution effect, probably attributed to the type of tested maize variety.

Stem and leaves of maize are generally considered as storage organs of nitrogen taken up during its pre-anthesis growth (Plénet and Lemaire 2000, Pommel et al. 2006). The importance of both organs as valuable sources of nitrogen for developing kernels was investigated by means of regression analysis (Table 6). A significant dependency of

Table 3. The SPAD index of the cob leaf at anthesis – BBCH 65 (mean for 2003–2007)

Nitrogen rate (A)	Fertilizer type (B)			Mean (A)
	NPK + Zn	NPK + Mg	NPK	
80 kg N/ha	730	721	690	714
140 kg N/ha	768	761	753	761
Mean (B)	749	742	722	–
LSD (A)		24**		
LSD (B)		20*		
Absolute control		627		

**$P < 0.01$; *$P < 0.05$

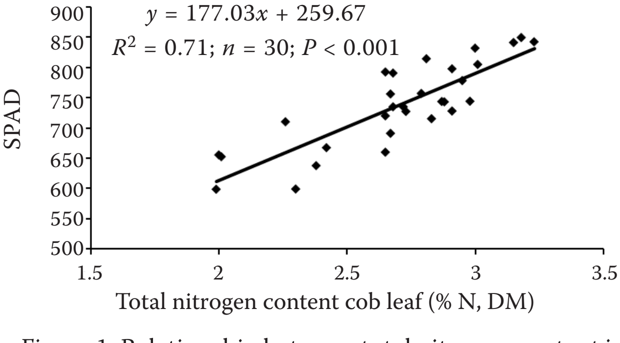

Figure 1. Relationship between total nitrogen content in the cob leaf at anthesis (BBCH 65) and the chlorophyll index (SPAD)

Table 4. Total nitrogen content (% N, DM) in maize parts at full maturity stage – BBCH 91, consecutive years of study

Years	Plant part				
	stems	leaves	kernels	cob cores	cob covering leaves
2003	0.80	1.06	1.66	0.46	0.45
2004	0.43	1.06	1.78	0.60	0.72
2005	0.53	0.84	1.66	0.54	0.52
2006	0.49	0.96	2.14	0.61	0.55
2007	0.58	1.28	1.51	0.56	0.66
LSD	0.10**	0.16**	0.11**	0.04**	0.20*
Mean (x ± SD)	0.57 ± 0.15	1.04 ± 0.20	1.75 ± 0.23	0.55 ± 0.06	0.58 ± 0.16
CV (%)	26.9	18.7	13.2	10.8	28.0

*P < 0.05; **P < 0.01

total nitrogen content in grain on its content in leaves was found, but it was limited only to the treatment with 80 kg N/ha. Yet, these relationships were found only for treatments supplied with zinc or magnesium on the background of 80 kg N/ha, as presented below:

NPK + Zn: $G_N = -2.431L_N + 4.064$; $R^2 = 0.79$; $n = 5$; $P < 0.01$

NPK + Mg: $G_N = -1.679L_N + 3.492$; $R^2 = 0.91$; $n = 5$; $P < 0.001$

Where: G_N – total nitrogen content in grain (%N DM), L_N – total nitrogen content in leaves (%N DM).

Based on these equations one can state, that the higher N concentration in leaves at harvest, the lower N content in grain is expected. Leaves of stay-green maize variety cannot be therefore considered as important nitrogen storage for developing kernels. Nevertheless, this relationship indirectly indicates their role in current photosyn-

Table 5. Total nitrogen content (% N, DM) in maize parts at full maturity stage – BBCH 91 (mean for 2003–2007)

Nitrogen rate (A)	Fertilizer type (B)			Mean (A)	*LSD* (A)	*LSD* (B)	Absolute control
	NPK + Zn	NPK + Mg	NPK				
Stem					ns	ns	0.57
80 kg N/ha	0.58	0.55	0.50	0.57			
140 kg N/ha	0.59	0.61	0.56	0.59			
Mean (B)	0.59	0.58	0.53	–			
Leaves					0.10*	ns	0.90
80 kg N/ha	0.95	1.02	0.98	0.98			
140 kg N/ha	1.10	1.10	1.09	1.10			
Mean (B)	1.03	1.06	1.03	–			
Kernels					ns	ns	1.61
80 kg N/ha	1.76	1.77	1.73	1.75			
140 kg N/ha	1.70	1.80	1.74	1.75			
Mean (B)	1.73	1.78	1.73	–			
Cob core					ns	0.02**	0.53
80 kg N/ha	0.54	0.52	0.54	0.53			
140 kg N/ha	0.56	0.58	0.58	0.57			
Mean (B)	0.55	0.55	0.56	–			
Cob covering leaves					0.10*	ns	0.57
80 kg N/ha	0.49	0.51	0.55	0.52			
140 kg N/ha	0.66	0.59	0.67	0.64			
Mean (B)	0.58	0.55	0.61	–			

**P < 0.01; *P < 0.05; ns – not significant

Table 6. Relationship between total nitrogen content in the vegetative parts and grain yield (n = 5)

Nitrogen rate (A)	Fertilizer type (B)	Indicative plant parts	
		stems	leaves
80 kg N/ha	NPK + Zn	–0.611	–0.887*
	NPK + Mg	–0.412	–0.951**
	NPK	–0.033	–0.358
140 kg N/ha	NPK + Zn	–0.498	0.124
	NPK + Mg	–0.212	–0.350
	NPK	–0.597	–0.280

**P < 0.01; *P < 0.05

thesis, responsible for extended period of carbon dioxide assimilation.

Total nitrogen uptake by maize crop and its accumulation in particular plant parts was significantly year-to-year variable (Table 7). Among the analyzed maize parts, the lowest variability was observed for kernels (CV = 18%), and at the same time the highest for cob covering leaves (CV = 46.5%). A particular attention should be however devoted to the indices of nitrogen economy of maize crop at full maturity, such as unit nitrogen uptake (UNU). Its CV was the lowest, indirectly underlying as generally constant conditions for nitrogen uptake by maize. Therefore, the UNU seems to be a universal index to describe nitrogen management by maize crop.

Total nitrogen accumulation by maize plant parts at full maturity was significantly affected by both experimental treatments (Table 8). Among five studied maize parts, kernels and cob covering leaves showed significant response to interactions of both experimental factors. It was found that plants fertilized with higher N rate were able to accumulate higher amounts of nitrogen. Both NPK mineral additives enforced TNC accumulation in kernels, with much deeper effect in the 80 kg N/ha treatment. For cob covering leaves, quite opposite patterns were found. In the treatment fertilized with 80 kg N/ha and supplied with zinc as well as for 140 kg N/ha treatment with magnesium, plants showed the lowest N accumulation. This is the indirect information about the specific effect of both elements on nitrogen remobilization from vegetative maize organs, lying next to developing kernels. Nitrogen accumulation in other vegetative maize parts was significantly affected only by N rate. Total uptake of nitrogen by maize crop at harvest showed, however, a significant dependence on both experimental factors, but without interactions occurring among them. Plants fertilized with 140 kg N/ha took up only 9% nitrogen more than those fertilized with 80 kg N/ha. In the light of previous data, the effect of mineral supplements was surprising, because no differences were found between the control plot (NPK) and those fertilized with zinc (NPK + Zn). In addition, a significantly lower N uptake was found for the magnesium plot (NPK + Mg). Relating total nitrogen uptake to its

Table 7. Nitrogen accumulation in maize parts and its total uptake and uptake indices, consecutive years of study (kg N/ha)

Years	Plant part							
	stems	leaves	kernels	cob cores	cob covering leaves	TU	UNU	NHI
2003	42.0	27.9	177.9	5.7	2.4	255.0	23.9	69.6
2004	23.1	24.4	181.9	8.5	6.1	244.0	23.9	74.5
2005	26.6	29.1	193.4	8.7	6.0	263.0	22.5	73.6
2006	31.2	32.8	212.8	8.7	5.2	291.0	29.2	73.3
2007	22.8	40.2	124.2	7.4	5.8	200.4	24.4	62.4
LSD	3.5**	3.9**	5.9**	0.8**	0.8**	9.1**	0.7**	1.8**
Mean (x ± SD)	29.1 ± 10.0	30.9 ± 9.6	178.0 ± 32.0	7.8 ± 1.9	5.1 ± 2.4	250.7 ± 34.6	24.8 ± 2.6	70.7 ± 6.0
CV (%)	34.6	30.9	18.0	24.3	46.5	13.8	10.6	8.3

**P < 0.01; TU – total uptake; UNU – unit nitrogen uptake, (kg N per 1 t of grain, including concomitant amount of N in vegetative parts); NHI – nitrogen harvest index (percentage share of nitrogen uptake by grains within its TU by the aboveground plant biomass)

Table 8. Nitrogen accumulation in maize parts at full maturity stage – BBCH 91 (kg N/ha) (mean for 2003–2007)

Nitrogen rate (A)	Fertilizer type (B)			Mean (A)	*LSD* (A)	*LSD* (B)	*LSD* (A × B)	Absolute control
	NPK + Zn	NPK + Mg	NPK					
Stem					2.2**	ns	ns	22.5
80 kg N/ha	30.5	26.9	25.1	27.5				
140 kg N/ha	30.6	31.3	30.5	30.8				
Mean (B)	30.6	29.1	27.8	–				
Leaves					2.5**	ns	ns	18.6
80 kg N/ha	27.4	29.5	30.3	29.0				
140 kg N/ha	31.8	32.6	33.8	32.7				
Mean	29.6	31.0	32.0	–				
Grain					2.2**	2.7**	3.8**	119.5
80 kg N/ha	177.2	175.7	164.3	172.4				
140 kg N/ha	183.2	186.4	181.5	183.7				
Mean	180.2	181.0	172.9	–				
Cob core					0.5**	ns	ns	5.9
80 kg N/ha	7.4	7.0	7.4	7.3				
140 kg N/ha	8.5	8.0	8.5	8.4				
Mean	8.0	7.5	8.0	–				
Cob covering leaves					0.5**	0.6**	0.9*	3.43
80 kg N/ha	3.9	4.1	5.0	4.3				
140 kg N/ha	6.2	4.8	6.7	5.9				
Mean	5.1	5.8	4.5	–				
Total					4.8**	5.9*	ns	169.9
80 kg N/ha	244.5	243.2	232.0	239.9				
140 kg N/ha	260.6	263.2	260.9	261.5				
Mean	252.5	246.4	253.1	–				

**$P < 0.01$; *$P < 0.05$; ns – not significant

content in plant parts, especially in kernels, it is necessary to state, that it was mainly a resultant of total aboveground biomass produced by maize. This conclusion supports the thesis developed by Boone et al. (1984), who found that grain N yield is more closely correlated with grain yield than with percentage of kernel N.

Nitrogen is considered as the most important nutrient for high grain yield on one hand, but as a nutrient potentially threatening to the environment, on the other hand. Therefore several attempts were undertaken for lowering its applied rates, mostly under agricultural ecosystems. According to Ma et al. (1999), maize crop was able to utilize on average ca 42–48% of nitrogen from ammonium saltpeter and at the same time it was showing a high seasonal variability. For maize grown under Polish conditions (Potarzycki 2009) these values reached 56–76% in different NPK treatments. Results obtained from the current study show that nitrogen recovery from ammonium saltpeter applied at the rate 80 kg N/ha was decidedly higher under zinc and magnesium-enriched NPK fertilizers and varied from 92–94% as compared to the control (NPK) where it amounted to 78% (Table 9). When the rate of fertilizer N was increased to 140 kg/ha, nitrogen recovery did not show any dependence on the NPK fertilizer mineral additives. For agricultural practices, this implies a reduction in the rates of applied nitrogen fertilizers under maize, provided a sufficient supply of plant with zinc or/and magnesium.

Table 9. Effect of fertilization treatments on nitrogen recovery at full maturity stage – BBCH 91 (mean 2003–2007), (%)

Nitrogen rate (A)	Fertilizer type (B)			Mean (A)
	NPK + Zn	NPK + Mg	NPK	
80 kg N/ha	94	92	78	88
140 kg N/ha	65	67	65	66
Mean (B)	80	80	72	–
LSD (A)		6**		
LSD (B)		8*		

**$P < 0.01$; *$P < 0.05$

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