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Original Research

Nitrogen Application Manner and Fertilization with Some Microelements Versus Ionic Equilibrium in Corn Grains

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Abstract

Investigations carried out in 2004-06 were aimed at determining effects of the nitrogen application manner and some top-dressed microelements on the content of cations and, in particular, their reciprocal ratios in grains of corn, cultivated to provide fodder. Except for sodium, and the K:Mg ion ratio, concentrations of cations and their ratios in corn grain were found to be significantly determined according to the way in which nitrogen was applied: higher contents of cations and more narrow values of studied ion ratios followed the application of a divided nitrogen dose to the soil and to the leaves. Top-dressing of microelemental fertilizers significantly shaped cation concentrations as well as values of ion ratios in corn grain, except for potassium and the Ca:Mg ratio. Application of microelements resulted in significantly higher contents of cations as compared to those in the control.

Keywords: corn grain, the method of nitrogen application, microelement fertilization, chemical composition, cation content, ion ratio

Introduction

Introduction to agricultural practice of new, high-yielding cultivable varieties and of modern means of production have resulted in an evident increase in area of corn cultivation as compared to that of the other cereals. The increased areas put under corn may lead to grain overproduction, and thus result in altered direction of its use. For instance, it may increase its use as a fodder. Fodder value is evaluated by the content of microelements and, in particular, by their reciprocal ratios [1]. Disturbed qualitative ratios or the excess or deficit of any alimentary components may result in the uptake of some other components, which do not always favourably affect fodder quality [1-3]. Among various agrotechnical procedures, fertilization with macro- and microelements exerts a particularly strong effect on chemical composition of plants and on ionic equilibrium [3-6]. A deficit in microelement content may lead to inhibition of specific enzymatic reactions and, finally, to deterioration of biological value and qualitative traits of the crop. Effects of microelements and, in particular, effects of their application in line with nitrogen on value of corn grain designed to be used as a fodder, have been insufficiently discussed in the literature [4-9]. This is particularly true in the case of new varieties of corn.

In view of the above, studies were undertaken to determine effects of the method in which nitrogen was applied and some top-dressed microelements on cation concentrations and their reciprocal ratios in corn grain, designed to be used as a fodder.

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Table 1. Cation contents in corn grain (mean values from three years 2004-06. mmol(+) kg^{-1}).

Nitrogen fertilization	Parameter	Corn cultivar							
		"LG 22.44"				"NYSA"			
		Microelement fertilization							
		B_0	B_1	B_2	B_3	B_0	B_1	B_2	B_3
150	K	83.6	79.2	76.9	80.8	81.5	87.6	85.4	87.2
100+50		89.0	84.9	81.8	85.9	84.4	88.0	86.7	87.4
mean		**86.1^x**	**82.0^x**	**79.2^x**	**83.3^x**	**82.8**	**87.7**	**85.9**	**87.2**
150	Mg	90.0 c	92.5 bc	95.8a	93.3 b	105.8*a	105.8*a	104.2*a	100.0*b
100+50		99.2 d	115.8 c	119.2 b	130.8 a	115.8*d	142.5*c	159.2*a	150.0*b
mean		**94.2^x**	**104.2^x**	**107.5^x**	**111.7^x**	**101.8^x**	**124.2^x**	**131.7^x**	**125.0^x**
150	Ca	12.5b	10.5c	13.4a	8.6d	9.4d	13.6a	12.4b	11.8c
100+50		8.9d	12.8b	12.0c	14.6a	11.7b	11.2c	12.1a	12.2a
mean		**10.7^x**	**11.6^x**	**12.7^x**	**11.5^x**	**10.5^x**	**12.4^x**	**12.2^x**	**12.0^x**
150	Na	3.8c	4.3a	4.2b	4.3a	4.7a	3.8c	4.5b	3.7d
100+50		3.6b	3.6b	3.5c	3.7a	3.7a	3.7a	3.3b	3.2c
mean		**3.7**	**3.9**	**3.8**	**4.0**	**4.2**	**3.7**	**3.9**	**3.5**

a,b,c,d - means marked in the rows with letters differ significantly statistically in dependence on the microelements used ($p < 0.05$);
* - higher means statistically different in dependence on corn cultivars ($p < 0.05$);
x - means differing significantly statistically in dependence on nitrogen fertilization manner ($p < 0.05$).

Materials and Methods

The studies were carried out in 2004-06 as a field experiment settled on the soil of IVa bonitation class, in Wieldządz (Cuiavia-Pomerania voivodship). The soil manifested a slightly acidic pH and an average content of available forms of phosphorus and potassium. The field experiment was set up in a system of randomized sub-blocks as a three-factor experiment with four replications. The experimental factors were as follows:

- factor I – corn cultivar of FAO 240 (n=2, LG 22.44, 'Nysa'),
- factor II – application of nitrogen (n=2, to the soil, to the soil + top-dressed):
  - 150 kg N·ha^{-1} before sowing, in the form of $CO(NH_2)_2$,
  - 150 kg N·ha^{-1} (2/3 +1/3), 2/3 of the dose to the soil (100 kg N·ha^{-1}),+1/3 of the dose (50 kg N·ha^{-1}) applied in the following manner: 20 kg N·ha^{-1} to the soil +30 kg N·ha^{-1}, top-dressed: in three sprays (1/3+1/3+1/3) every other ten days at the phase of the fifth leaf, in the form of 10% solution of urea),
- factor III – microelement fertilizers applied in parallel with nitrogen at the phase of the fifth leaf, (n=4, B0- control object, B_1-ADOB Zn, B_2-ADOB Cu, B_3-Basfoliar 36 Extra).

Agricultural procedures as well as the remaining agrotechnical elements followed recommendations for corn cultivation designed for fodder. Phosphorus and potassium fertilizers were applied in the following doses: 100 kg P_2O_5·ha^{-1} – in the form of triple superphosphate,150 kg K_2O·ha^{-1} – in the form of a high percentage potassium salt.

The corn grains were analyzed for chemical composition (K, Mg, Ca, Na) and ionic ratios were calculated. Concentrations of potassium, calcium, and sodium were estimated by flame photometry and content of magnesium by atomic spectroscopy, with the use of an ASS-1 apparatus. The obtained results were subjected to statistical analysis employing analysis of variance, using a model consistent with the experimental set-up and using Tukey test to evaluate significance of differences.

Results and Discussion

Maintenance of ionic equilibrium in a plant represents the indispensable condition of a plant's quality. Contents of mineral components in a plant is a result of several variables, i.e. it depends on soil/climatic conditions, including soil pH, dynamic activity of soil solution, applied agrotechnical procedures, mainly fertilization and genetic features of the cultivated plants [8-12].

The content of studied cations in corn grain designed to be used as fodder were found to be significantly determined by studied factors, and magnesium content was in addition significantly affected by all the potential interactions between the factors (Table 1). Content of the cation fitted the range of 90.0 to 159.2 mmol(+)·kg^{-1} dry mass. It should be mentioned that magnesium content, expressed in ionic equivalents, was the highest among the studied cations.

In the corn grain of 'Nysa' cultivar, the statistically highest magnesium content was found after the use of the divided nitrogen dose and top-dress application ob both copper and Basfoliar 36 Extra (B3) . The values were by 37.5 and 29.5% higher in relation to corn samples where no microelements were used. It should be stressed that top-dress application of microelements, which determine several physiological functions in a plant, resulted in an increased content of magnesium in the grain, as compared to the control. Optimum content of magnesium in corn grains amounts to 1.8 g·kg^{-1} [13]. In the conducted studies, on the other hand, the mean content amounted to 112.5 mmol(+)·kg^{-1} dry mass, which corresponded to 1.35 g·kg^{-1}, and it was lower by 25% than the value given as optimum by the above-quoted authors (Table 1).

Content of calcium in the grain of corn was relatively low and, on average, it ranged between 8.6 and 14.6 mmol(+)·kg^{-1} [14]. The values were significantly determined by the way of nitrogen application, epighytic application of microelements and their potential interactions. Similarly as in the case magnesium, a generally significantly higher content of calcium was noted after the application of divided doses of nitrogen. According to Janukowicz [1] fertilization with nitrogen stimulates a very fast growth in plant mass, which causes plants to be unable to absorb amounts of Ca^{2+} ions sufficient for the growth of their mass. Deficits in Ca^{2+} ions in plants may be compensated by, i.e., Mg^{2+} ions [15]. It should be stressed that in the conducted studies, mean content of magnesium in corn grain were almost tenfold higher than the content of calcium.

Top-dress application of Basfoliar 36 Extra on the background of the divided nitrogen dose was followed by a significant increase in calcium content in the grain of the 'LG 22 44' cultivar by as much as 64%, as compared to the control (B_o). In the case of the 'Nysa' cultivar, the highest comparable values were found also after application of the divided nitrogen dose and ADOB Cu or Basfoliar 36 Extra, but they were only 4% higher in relation to the control.

Mean content of potassium in corn grain ranged between 76.9 and 89.0 mmol(+)·kg^{-1} and it was significantly dependent on the way in which nitrogen was applied. A significantly higher content of the cation, independent from a cultivar under study, was observed after nitrogen was applied in a divided dose (2/3 + 1/3). Significantly higher differences in amounts of this cation were observed in the grain of the 'LG 22 44' cultivar collected from the object top-dressed with ADOB Zn. Literature of the subject provides no unequivocal data on the effect of nitrogen fertilization on potassium content in corn grains [10, 16-19]. Nitrogen fertilization is known to affect absorption of potassium ions by plants and the effect is two-fold. Ammonium ion, with electric charge and electron affinity resembling those of potassium ion and an almost identical diameter of hydrated ions, may compete with potassium for sites on ion carrier [20]. According to a distinct opinion, on the other hand, the absorbed ammonium ions are rapidly incorporated to organic compounds and the developed deficit of positive charge is balanced first of all by K^+ ions and, to a lower extent, by the remaining cations [1].

Sodium content in corn grain ranged from 3.2 to 4.7 mmol(+)·kg^{-1} and was significantly dependent only on the applied fertilization with microelements and interaction of experimental factors, except of interactions between corn

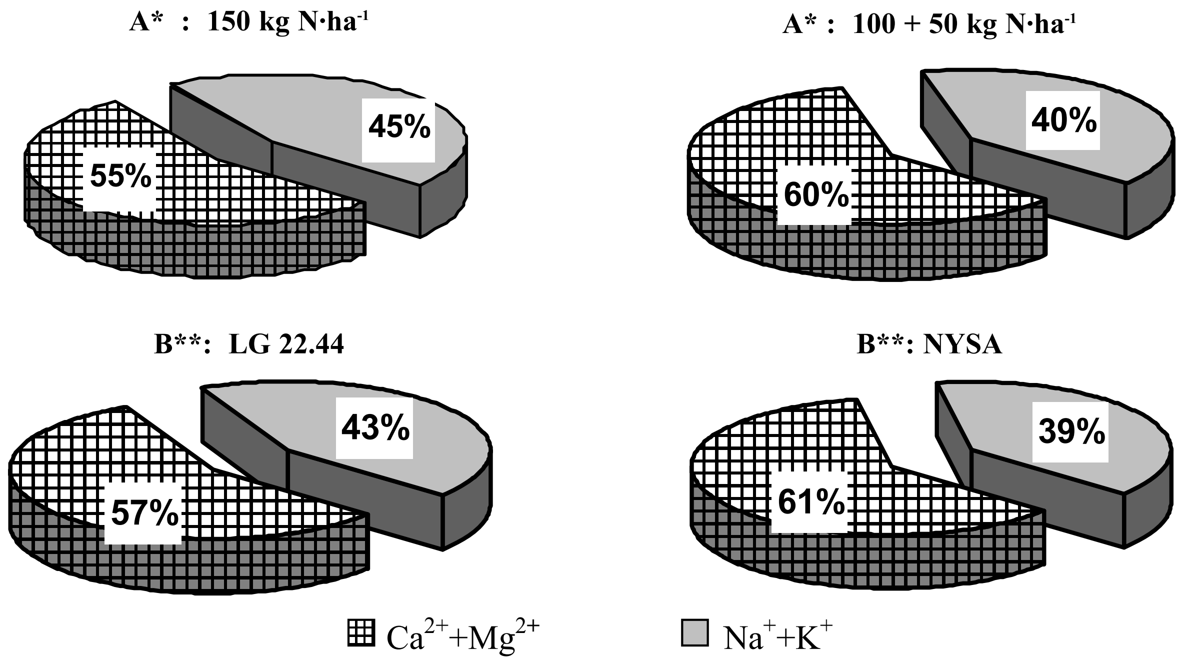

Fig. 1. The shares sum of uni- and bivalent cations in the studied cations. A* – nitrogen application, B** – corn cultivar.

Table 2. Ionic ratios in grain corn (mean values from three years 2004-06).

Nitrogen fertilization	Parameter	Corn cultivar							
		"LG 22.44"				"NYSA"			
		Microelements fertilization							
		B_0	B_1	B_2	B_3	B_0	B_1	B_2	B_3
150	K:Mg	0.93	0.86	0.80	0.87	0.77	0.83	0.82	0.87
100+50		0.90	0.73	0.69	0.66	0.73	0.62	0.54	0.58
mean		**0.91**	**0.79**	**0.74**	**0.76**	**0.75**	**0.72**	**0.68**	**0.73**
150	Ca:Mg	0.14	0.11	0.14	0.09	0.09	0.13	0.12	0.12
100+50		0.10	0.11	0.10	0.11	0.10	0.08	0.08	0.08
mean		**0.14^x**	**0.11**	**0.12^x**	**0.10**	**0.09**	**0.10^x**	**0.10^x**	**0.10^x**
150	K:Na	22.00*a	18.42c	18.31c	18.79b	17.34d	23.05*b	18.98*c	23.57*a
100+50		24.72*a	23.58b	23.37bc	23.22c	22.81a	23.78*c	26.27*b	27.31*a
mean		**23.36^x**	**21.00^x**	**20.84^x**	**21.00^x**	**20.10^x**	**23.42^x**	**22.62^x**	**25.44^x**
150	K:(Ca+Mg)	0.82*a	0.77*b	0.70c	0.79b	0.71b	0.73b	0.73b	0.78a
100+50		0.82*a	0.66*b	0.62*c	0.59*d	0.66a	0.57b	0.51d	0.54c
mean		**0.82**	**0.71^x**	**0.66^x**	**0.69^x**	**0.68^x**	**0.65^x**	**0.62^x**	**0.66^x**
150	K+Na:Ca+Mg	0.85*a	0.81*b	0.74c	0.84*a	0.75c	0.77b	0.77*b	0.81a
100+50		0.86*	0.69*	0.65*	0.62*	0.69	0.60	0.53	0.56
mean		**0.85**	**0.75^x**	**0.69^x**	**0.73^x**	**0.72^x**	**0.68^x**	**0.65^x**	**0.68^x**

a,b,c,d - means marked in the rows with letters differ significantly statistically in dependence on the microelements used ($p < 0.05$);
* - higher means statistically different in dependence on corn cultivars ($p < 0.05$);
x - means differing significantly statistically in dependence on nitrogen fertilization manner ($p < 0.05$).

cultivar and the way in which nitrogen was applied (Table 1). As compared to the control, a significantly higher sodium comparable content was noted in the 'LG 22 4' grain following application of microelements and nitrogen, while in general a significantly lower sodium content was observed for 'Nysa'.

Independently of the applied factors, i.e. cultivar of corn, the manner of nitrogen application and application of the used microelements, contents of studied elements expressed in equivalents formed the following sequence: Mg >K >Ca> Na.

A reciprocal interaction of ions may involve their antagonism, blockade or mobilization, reciprocal precipitation or a synergism. The sum of uni- and bivalent cations provides an important index of ionic equilibrium, which determines nutritional value of a fodder [16, 17, 19, 21]. In present studies, a definitely higher value of the sum of bivalent cations was noted as compared to the sum of monovalent cations (Fig. 1). On average, the most pronounced difference between the studied sums was observed in the corn grains of 'Nysa' cultivar or following the application of nitrogen in a divided dose (2/3 +1/3), which amounted to 22% and 20%, respectively. Absorption of ions by the plants depends, i.e., on the capacity of their roots to exchange cations. Dicotyledons of a high sorption capacity absorb more bivalent cations (Ca^{2+}, Mg^{2+}), while monocotyledons absorb more univalent cations (K^+, Na^+) [1, 21]. In our studies, such tendencies have not been confirmed.

Absorption of macroelements by plants affects values and ranges of the rations, which are extremely important in animal nutrition. Excessive range of ratios such as K:Ca, K:Mg, K:(Ca+Mg) etc. may represent one of the causes of hypomagnesaemia in farm animals [1, 3, 7, 8, 16, 22].

Within our studies, reciprocal relations between studied cations have been calculated and they have proven to be markedly lower than the optimum ratios provided by literature sources [1, 3, 7] (Table 2). It has been found that the value of the Ca:Mg ratio has depended exclusively on the manner of nitrogen application while values of K:Na, K:(Ca+Mg) and (K+Na):(Ca+Mg) ratios have been affected by all studied variables and by their interactions. In general, values of the ratios have become more narrow following the administration of nitrogen in a divided dose (2/3 + 1/3) as compared to the use of a single dose. The only exception was the K:Na ratio. Values of K:(Ca+Mg) and (K+Na):(Ca+Mg) ratios have been determined by variety

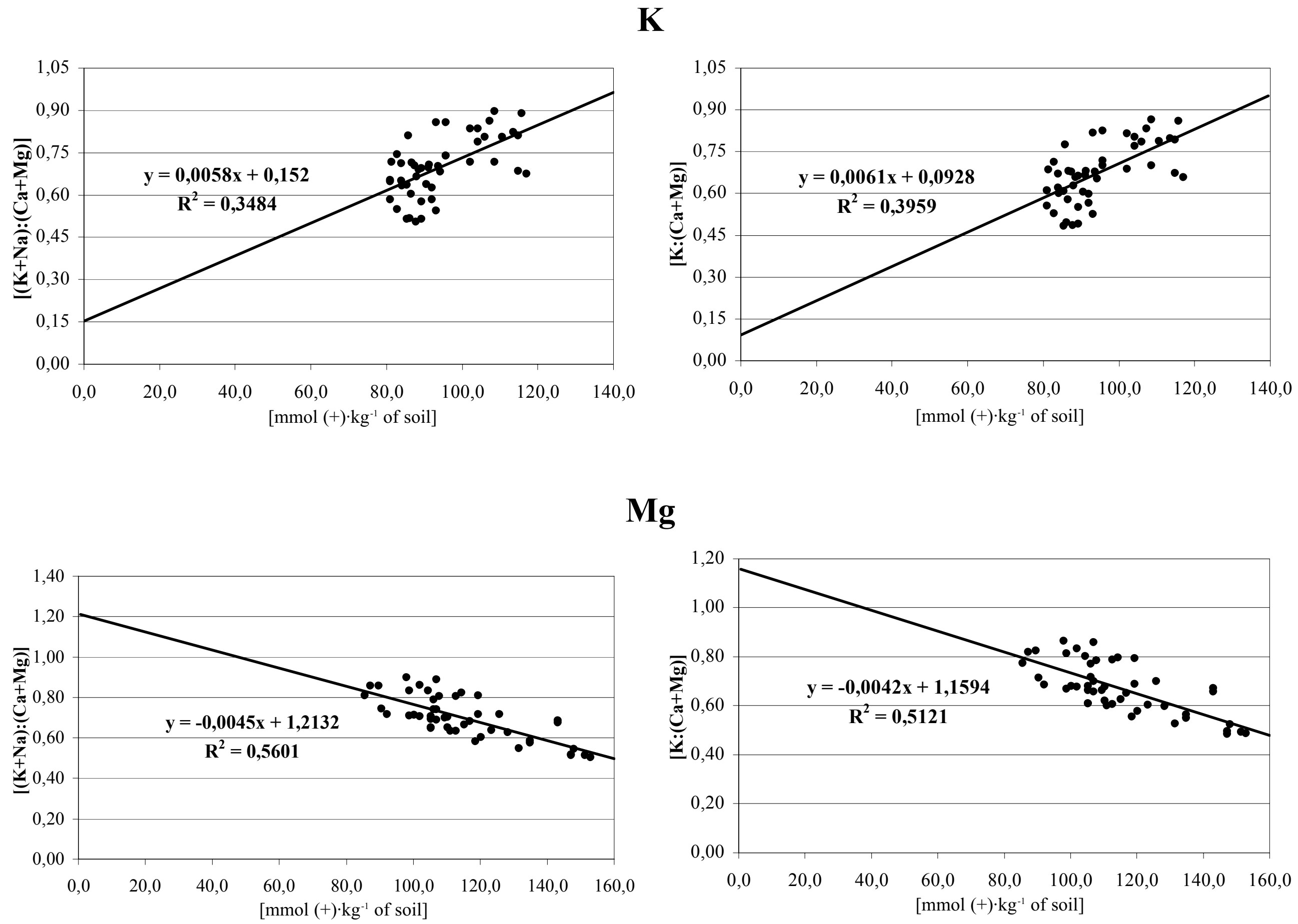

Fig. 2. The dependences between ionic ratios and the potassium and magnesium contents of corn grain.

traits and in the corn grains of 'Nysa' cultivar they have been significantly more narrow as compared to those obtained for the grains of 'LG 22.44' cultivar. Following application of the tested microelement fertilizers, the values of ion ratios also have become narrower than those in the control. The above-discussed values of ion ratios have been found to be significantly correlated with contents of potassium and magnesium in the corn grain (Fig. 2). The ratios of K:(Ca+Mg) and (K+Na):(Ca+Mg^{2+}) have manifested a negative correlation with magnesium content and a positive correlation with potassium content. On the basis of the calculated equations of linear regression, the strongest of relationships has been noted for potassium and K:(Ca+Mg) ratio, as proven by the regression coefficient.

The obtained values of ion ratios differ from the respective data in the literature [1, 3, 7, 8, 16, 17]. At low temperatures and at low air humidity, plants restrict uptake of cations while at higher humidity cations are accumulated in the plants [16, 17, 23]. It should be noted that in the years of the experiment (2004-06), July, in which corn manifests the highest requirement for water, has been very dry. The sum of atmospheric precipitation in July, calculated for the three years, has amounted to just 37 mm and has been as much as 2.5-fold lower than that calculated for multiple years (91 mm).

Conclusions

1. Mean content of cations in corn grain manifested a significant variability and it could be ordered in the following sequence: Mg >K >Ca> Na. As a result, the contents in general induced narrowing of the studied values of ion ratios.
2. Except for sodium, and the K:Mg ion ratio, concentrations of cations and their ratios in corn grain were found to be significantly determined by the way in which nitrogen was applied: higher contents of cations and more narrow values of studied ion ratios followed application of a divided nitrogen dose to the soil and to the leaves.
3. Top-dressing with the examined microelement fertilizers significantly shaped cation content and values of ion ratios in corn grain, except for potassium and Ca:Mg ratio. Application of microelements resulted in higher cation contents, as compared to the control.

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