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AN ASSESSMENT OF THE EFFECT OF POTASSIUM FERTILIZING SYSTEMS ON MAIZE NUTRITIONAL STATUS IN CRITICAL STAGES OF GROWTH BY PLANT ANALYSIS

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Abstract

Yield of maize depends on nitrogen supply to the plant at critical stages of the formation of main yield components. In the rain-fed production system, the productivity of applied nitrogen is conditioned by water supply to growing crop. Potassium is considered to be a nutrient significantly affecting water use by crops. Therefore, an in-season nitrogen balance is needed to adjust N levels and predict yields. These assumptions were validated in a long-term static field experiment with four levels of potassium fertilizing. They were differentiated by two soil fertility levels (Medium, High) and applied fertilizer (K-, K+). The nutritional status of maize was evaluated at two stages: 5th leaf and the beginning of flowering, using three approaches: i) nutrient concentration, ii) nitrogen to other nutrient ratios, iii) DRIS (Diagnosis Recommended Integrated System) method. These studies showed that potassium management was the key contributor to the year-to-year grain yield variability. Thus, grain yield was the basis for verification of the tested indices. At the 5th leaf stage only phosphorus (concentration and N/P ratio) can be considered as a potential predictor of the final yield of grain. The ear leaf as a vegetative part proved to be useful for evaluation of nutritional indices in maize and for making predictions about yield. The optimal system of potassium management can be defined according to its impact on the N/K, N/Mg and N/Ca ratios and, consequently, on yields of maize. The N/K ratio reached the saturation status, as presented by the quadratic regression model. The other two ratios affected grain yield in accordance to the linear regression model. The applied DRIS procedure corroborated the importance of potassium management as a factor significantly affecting the nutritional balance in maize. This crop has a potential to produce high yield of grain on medium K fertile soil provided potassium fertilizer is supplied whenever needed.

Keywords: maize, nutrient concentration, nitrogen to nutrient ratios, DRIS, critical stadia of nutrient evaluation.

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OCENA WPŁYWU SYSTEMU NAWOŻENIA POTASEM NA STAN ODŻYWIENIA KUKURYDZY W KRYTYCZNYCH FAZACH WZROSTU METODĄ ANALIZY ROŚLINNEJ

Abstrakt

Plon kukurydzy zależy od stanu zaopatrzenia rośliny w azot w krytycznych fazach formowania elementów struktury plonu ziarna. W naturalnych warunkach produkcji efektywność azotu jest uwarunkowana stanem zaopatrzenia rośliny w wodę. Potas jest uznawany za czynnik wpływający na wykorzystanie wody przez rośliny uprawne. Zatem w okresie wegetacji jest konieczny bilans żywieniowy azotu, zarówno do jego korekty, jak i predykcji plonu. Przyjęte założenia zweryfikowano na podstawie wieloletniego stałego doświadczenia polowego z zastosowaniem 4 systemów gospodarki potasem określonej na podstawie poziomów żyzności gleby (średni, wysoki) i bieżąco stosowanego nawożenia potasem (K-, K+). Stan odżywienia kukurydzy określono w stadium 5. liścia i na początku kwitnienia. Sposób gospodarowania potasem okazał się głównym czynnikiem zmienności plonów ziarna w latach, co przyjęto jako podstawę do weryfikacji testowanych indeksów. W stadium 5. liścia tylko fosfor (koncentracja, stosunek N do P) można rozważać jako potencjalny predykator plonu ziarna. Liść podkolbowy okazał się częścią rośliny przydatną do opracowania zarówno indeksów stanu odżywienia, jak i predykcji plonu ziarna. Optymalny system gospodarki potasem można określić, bazując na wpływie tego czynnika na wielkość stosunków N do K, N do Mg i N do Ca, a w konsekwencji na plon ziarna. Stosunek N do K osiągnął stan wysycenia, na co wskazuje uzyskany model regresji 2° i wyznaczone optimum. Pozostałe stosunki kształtowały plon ziarna zgodnie z modelem regresji liniowej. Zastosowana procedura DRIS potwierdziła znaczenie gospodarki potasem jako czynnika istotnie kształtującego stan bilansu żywieniowego kukurydzy. Ta roślinna ma duży potencjał do produkcji ziarna na glebach o średniej zasobności w potas, pod warunkiem bieżącego nawożenia tym składnikiem.

Słowa kluczowe: kukurydza, koncentracja składników pokarmowych, stosunek azotu do składników pokarmowych, DRIS, krytyczne stadia oceny stanu odżywienia.

INTRODUCTION

Yield of maize depends on nitrogen supply to plant at critical stages of two principal components of grain yield formation. The first one, establishing during the vegetative period of maize growth, is the number of kernels per plan (NKP). The second one, weight of the individual kernel, in practice used as 1000 kernel weight (TKW), reveals during the grain filling period (Otegui, Bonhomme 1998). Both components create as a sink for carbohydrates produced by leaves, considered as the source of assimilates. The critical period for the NKP extends from the stage of 8th leaf (BBCH 18) up to the stage of watery ripe of maize (BBCH 71) (Grzebisz et al. 2008*b*, Subedi, Ma 2005). In rain-fed agricultural systems, the productivity of applied nitrogen is conditioned by water supply to growing crop. Water, because of its scarcity should be used with the highest efficiency, which in turn is governed by plant nutritional status. Potassium due to its impact on many physiological processes plays an important role in water use by crop plants (Grzebisz et al. 2013, Oosterhuis et al. 2013).

An effective system of maize plant nutritional status evaluation requires an implementation of very reliable analytical tools. Tissue analysis seems to be the useful method for making a quick assessment of nitrogen status in maize during the whole period of the NKP formation. The reliability of tissue analysis and resulting fertilization recommendations require an accuracy in six following steps of conducted diagnosis: i) method of plant part sampling, ii) laboratory methods of nutrient concentration determination, iii) standard nutrient ranges for laboratory data comparison, iv) interpretation procedures of the obtained data, v) methods for working out fertilizing recommendations, and vi) a simplicity of the advisory report (PARENT 2011). Most of this method relies on a fixed concentration range of a given nutrient in the indicative plant part, termed as the saturation level/range (JONES et al. 1990). It is assumed that a crop at the saturation range can reach the maximum productivity. Tissue analysis in maize is the most advanced for the ear leaf, considered as the stage the most sensitive with respect to the NKP formation (JONES et al. 1996). Therefore, the most standard ranges and research studies are broadly devoted to this particular stage of maize development (CAMPBELL, PLANK 2000, JONES et al. 1990, POTARZYCKI 2010). The Diagnosis and Recommended Integrated System is one of the most sophisticated analytical tool for maize nutritional status assessment. This method relies on the relationship between studied nutrients and defined standards (ELWALI et al. 1985).

The most advantage of ear leaf analysis is to make a yield prediction (SOLTANPOUR et al. 1995). The main disadvantage is low practical applicability of obtained models. In spite of this stage proximity to flowering, there is no chance to make corrections of maize nutritional status. Simply, this is the end of vegetative growth. For diagnostic purposes much more important are the earliest stages, just before the inflorescences set up. At this particular stage, maize reaches the highest rate of absolute growth, significantly affected by nitrogen supply (GRZEBISZ et al. 2010*a*). There are only a few papers concerning maize nutritional status at the stage of 5th leaf (GRZEBISZ et al. 2008*a*, MALLARINO, HIGASHI 2009).

The key objective of the conducted study was to assess maize nutritional status, oriented on nitrogen balancing, under conditions of four long-term potassium fertilizing systems. The second objective was to compare the final yield predictive usability of two stages of maize growth, i) 5th leaf, and ii) ear leaf at the beginning of flowering.

MATERIALS AND METHODS

Study on nutritional status of maize (variety *Eurostar,* FAO 240) in response to four potassium fertilizing treatments, existing in the long-term experiment (1991), was carried out during three consecutive growing seasons

2004, 2005 and 2006 at RGD Brody (Poznan University of Live Sciences Experimental Station; 16°28'E i 52°44'N). The experimental trial was established on a soil originated from a loamy sand underlined by light loam soil and classified accordingly to Polish as the light soil. The field trial arranged as a three-factorial split-block design, replicated four times, consisted of following factors:

1. Potassium soil fertility level: M (medium); H (high);
2. Potassium rates: - K; + K (100 kg K ha^{-1});
3. N rates: 0, 100, 150 and 200 kg N ha^{-1}.

The tested systems of potassium fertilization are a combination of: i) medium K fertility level without and with fertilizer potassium application (acronym MK-, MK+, respectively), ii) high soil K fertility level without and with fertilizer potassium application (HK-, HK+).

The plant material for the analysis was collected at two stages of maize growth: 5^{th} leaf (BBCH 15) and at the beginning of anthesis (BBCH 61). The individual sample comprised 12 plants per plot, or ear leaves. The samples were dried in 65°C to the constant weight, ground and analyzed for concentration of nitrogen, phosphorus, potassium, magnesium, calcium, copper, zinc and manganese. Nitrogen concentration in plant material was determined by the Kjeldahl method; potassium, calcium, magnesium, zinc, copper and manganese by the FAAS method (Flame Atomic Absorption Spectrophotometry, Varian 250 plus); phosphorus – colorimetrically (Analitykjena Specord 40). Concentrations of all nutrients were expressed on a dry weight basis.

The interpretation of data was conducted by three analytical tools. The first, based on *the saturation level approach*, allows to compare data sets of a given nutrient concentration in plant samples with standard ranges. The second, applied in this study relied on nitrogen ratios with other studied nutrients. Following sets of nutrient's pair was calculated: N/P, N/K, N/Mg, and N/Ca. The Diagnosis and Recommendation Integrated System (DRIS) was used to interpret the complex plant tissue nutrient ratios (WALWORTH, SUMMER 1987).

DRIS indices were then calculated according to following formulae, example for nitrogen:

$$I(N) = (f(N/P) + f(N/K) + f(Mg/N) + f(Ca/N))/ 4$$

when N/P > n/p than $$f(N/P) = \left[\frac{N/P}{n/p} - 1\right] \cdot \frac{1000}{CV}$$

when N/P < n/p than $$f(N/P) = 1 - \left[\frac{n/p}{N/P}\right] \cdot \frac{1000}{CV}$$

where,

N/P – nutrient ratio of N to P contents in the studied crop,
n/p – nutrient ratio of N to P in the DRIS norm (Table 1)
CV – coefficient of variation for n/p ratio for the DRIS norm,
1000 – coefficient of recalculation.

Table 1

A statistical evaluation of nutrient relationships in the ear leaf of maize at the stage of the beginning of anthesis (ELWALI et al. 1985)

Nutrient ratios	Number of observations in the data bank	Mean*	Standard deviation (SD*)
n/p	1909	9.035	2.136
n/k	1908	1.463	0.426
p/k	1909	0.169	0.054
ca/n	1553	0.160	0.057
ca/P	1554	1.447	0.612
ca/k	1553	0.237	0.122
mg/n	1556	0.071	0.029
mg/p	1557	0.639	0.330
mg/k	1556	0.104	0.063
mg/ca	1554	0.465	0.182

* for yielding population in the whole set of examined data

The diagnostic procedure consists of two related stages, calculation of nutrient indices and their interpretation against the DRIS norms. The DRIS norms for maize by ELWALI et al. (1985) were used in this study (Table 1). The sum of indices with recognition of its signs (plus and minus) is always zero. The sum of indices without recognition of its signs, called absolute sum of indices ASI, is as closer to zero as more balanced plant nutritional status is.

RESULTS AND DISCUSSION

Maize at the stage of 5th leaf – BBCH 15

Up to the stage of 5th leaf maize was supplied with 100 kg N ha^{-1} (Table 2). Under Polish conditions, this rate is considered as an optimal for maximizing maize grain yield (KRUCZEK 2005, GRZEBISZ et al. 2010*a*). At this stage of growth maize achieved a sufficiency level of nutrient concentration for nitrogen, potassium, but not for phosphorus and magnesium (SCHULTE, KELLING 1991). The concentration of all nutrients showed a significant year-to-year variability. The highest was observed for potassium. In maize plants grown in 2004, K concentration was twice as low compared to 2005. The latter was the year with the highest yield of grain. *The dilution effect* was noted for magnesium and calcium. Effect of potassium fertilizing systems was significant for all nutrients. Except potassium, a slight declination trend in response to freshly applied potassium fertilizer was also observed for magnesium and calcium. Therefore, this relationship can be considered as the first signal for potential antagonism on plots fertilized with potassium.

Table 2

Nutrient concentration in maize at the stage of 5th leaf (g kg^{-1} DM)

Main factor	Level of the factor	N	P	K	Mg	Ca
Years	2004	38.46^{b}	2.822^{a}	21.72^{a}	1.907^{b}	7.322^{b}
	2005	40.53^{a}	2.929^{a}	43.77^{c}	1.294^{a}	6.457^{a}
	2006	41.22^{a}	3.794^{b}	35.83^{b}	1.939^{b}	7.793^{c}
	F	6.230**	23.70***	123.0***	23.11***	21.89***
Potassium fertilizing systems	MK-	41.53^{b}	3.286^{b}	27.00^{a}	2.079^{b}	7.775^{b}
	MK+	39.23^{a}	3.061^{a}	34.51^{ab}	1.713^{ab}	6.891^{a}
	HK-	40.47^{a}	3.414^{b}	35.35^{ab}	1.649^{ab}	7.380^{ab}
	HK+	39.06^{a}	2.966^{a}	38.24^{b}	1.413^{a}	6.716^{a}
	F	3.010*	2.618*	16.97***	9.985***	8.258***
Nitrogen rates	0	38.54^{a}	3.158	34.35	1.633^{a}	6.784^{a}
	100	41.60^{b}	3.205	33.20	1.794^{b}	7.597^{b}
	F	21.10***	0.141	0.980	3.396*	23.61***

^{a} numbers marked with the same letters are not significantly different; *** -. **. * - probability level at 0.001; 0.01; 0.05 respectively

Among the considered nutrients, only potassium showed a significant year-to-year variability (Figure 1). In the semi-dry, 2004, K concentration was low, on average amounting to 20 g kg^{-1}, in fact, indicating a status of maize plant malnutrition. In addition, any impact of potassium management on its concentration was observed. In 2005, K concentration was the highest, showing the increasing trend in accordance to supply of potassium, both from soil and fertilizer resources (GRZEBISZ, OERTLI 1994). This is in

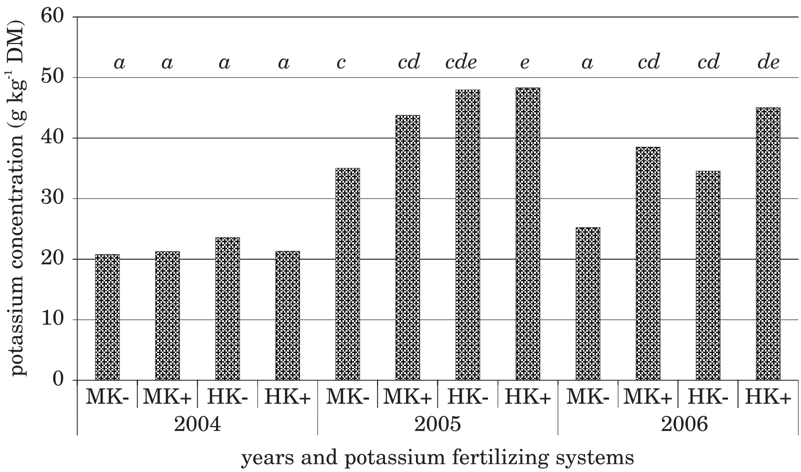

Fig. 1. Effect of potassium fertilizing systems on potassium concentration in maize at the stage of 5th leaf in consecutive years

agreement with Grzebisz et al. (2013), who presented an opinion that the elevated K nutritional status at initial stages of crop growth is a prerequisite of high yield. In 2006, at the stage of 5th leaf, K concentration in maize was significantly affected by freshly applied K fertilizer. It can be therefore concluded, that at the stage of 5th leaf, K nutritional status is not a decisive factor of final grain yield of maize.

The analysis of ratios between nitrogen and other nutrients showed a decisive impact of the course of weather, followed by potassium fertilizing systems (Table 3). The highest year-to-year variability was noted for N/K pair, followed by N/Mg and N/P. In the first case, this ratio was the narrowest in 2005, and the broadest in 2004. The reverse relation was found for N/Ca. Effect of potassium fertilizing systems was significant for two pairs, i.e., N/K and N/Mg. In both cases it was the broadest for maize plants

Table 3

A statistical evaluation of nutrient ratios in maize at the stage of 5th leaf

Main factor	Level of the factor	N/P	N/K	N/Mg	N/Ca
Years	2004	14.16[b]	1.811[c]	20.73[a]	5.282[a]
	2005	14.03[b]	0.959[a]	33.79[b]	6.376[b]
	2006	11.03[a]	1.248[b]	22.90[a]	5.379[a]
	F	32.45***	100.5***	51.31***	23.80***
Potassium fertilizing systems	MK-	13.18	1.655[b]	21.22[a]	5.466
	MK+	13.08	1.277[a]	25.97[b]	5.768
	HK-	12.61	1.267[a]	27.08[b]	5.576
	HK+	13.43	1.158[a]	28.95[b]	5.906
	F	0.916	19.00***	8.507***	1.874
Nitrogen rates	0	12.60[a]	1.296	26.26	5.816
	100	13.55[b]	1.383	25.35	5.543
	F	6.907*	3.020	0.655	3.634

[a] numbers marked with the same letters are not significantly different; ***. **. * – probability level at 0.001; 0.01; 0.05 respectively

grown in the control K plot (MK-). In addition, both pairs showed a considerable year-to-year variability. Therefore, the respective ratios were regressed against yield of grain (GY). The N/K relationship was significant provided years with drought were considered:

$$GY = 1758N/K + 4117 \text{ for } n = 8, R^2 = 0.6 \text{ and } P \leq 0.01$$

The N/Mg relationship was, however, significant when the semi-dry year, i.e., 2004, was excluded from calculation:

$$GY = 93.85N/Mg + 4202 \text{ for } n = 8, R^2 = 0.5 \text{ and } P \leq 0.05$$

Table 4

Coefficients of correlation for grain yield versus nutrient ratios at the stage of 5th leaf (n = 6)

Main factor	Level of the factor	N/P	N/K	N/Mg	N/Ca
Potassium fertilizing systems	MK-	0.891**	-0.43	0.637	0.477
	MK+	0.773*	0.160	0.581	0.522
	HK-	0.708*	-0.01	0.255	0.122
	HK+	0.856**	0.306	0.389	0.382

**. * – probability level at 0.01; 0.05 respectively

It can be concluded, based on the obtained data that both ratios limited yield of grain, but only in years with pronounced drought. This conclusion is in agreement with an opinion expressed by Grzebisz et al. (2013), Grzebisz (2013), Potarzycki (2011) concerning yield forming effect of potassium and magnesium in crop plants.

The detailed study on the effect of potassium fertilizing systems on ratios between nitrogen and other nutrients, implicitly showed on the decisive rule of N/P (Table 4). It was reliable, irrespective of the tested system of potassium fertilizing. Therefore, this pair can be used as a predictor of final yield of maize. This conclusion corroborates studies by Kruczek (2005). The author showed that maize is highly sensitive to phosphorus supply, and its effect is first measurable at the stage of 5th leaves.

The ear leaf – BBCH 61

The ear leaf is the most frequently plant part used in evaluation of maize nutritional status at the beginning of maize flowering (Jones et al. 1990, Campbell et al. 2000). The highest year-to-year variability of nutrient concentration in the tested maize part was observed for phosphorus, followed by nitrogen and magnesium (Table 5). Phosphorus concentration in 2005 was twice as high as in 2006. It is necessary to stress that the highest yield of maize was harvested in 2005 and the lowest in 2006. The same trend, but with slightly lower differences between years, were noted for magnesium. The obtained data sets, based on averages for each particular year, were compared to published standards and/or to be recently published research data (Table 6). Nitrogen and phosphorus concentrations, except 2006, were within standard ranges. Potassium concentration was in the sufficiency range, but only in two contrasting years, 2005 and 2006. The much lower value, as determined, in 2004 can be considered as *the effect of K dilution*. Concentration of magnesium fulfilled the condition of the range by Campbell et al. (2000). It was, however, much below the lower limit in years with water stress. In the case of calcium, its concentration was above standard ranges by Jones et al. (1990) and Potarzycki (2010).

Effect of potassium fertilizing systems on nutrient concentration in the ear leaf were significant for potassium, magnesium and calcium. Potassium concentration was significantly higher in plants grown on the K HK system

Table 5

Nutrient concentration in the cob leaf at the stage of the beginning of anthesis (g kg^{-1} DM)

Main factor	Level of the factor	N	P	K	Mg	Ca
Years	2004	34.77^{c}	2.686^{b}	14.58^{a}	2.169^{b}	6.302^{b}
	2005	31.15^{b}	3.887^{c}	18.76^{b}	2.678^{c}	5.623^{a}
	2006	18.33^{a}	1.987^{a}	18.66^{b}	1.831^{a}	6.115^{b}
	F	442.2***	150.7***	75.06***	76.35***	20.14***
Potassium fertilizing systems	MK-	27.21	2.675	16.47^{a}	2.636^{c}	6.540^{c}
	MK+	28.06	2.925	16.71^{a}	2.179^{b}	5.911^{b}
	HK-	28.11	2.814	18.10^{b}	2.194^{b}	6.024^{b}
	HK+	28.94	3.000	18.05^{b}	1.895^{a}	5.580^{a}
	F	2.220	2.457	7.300***	29.56***	19.48***
Nitrogen rates	0	24.31^{a}	2.754	17.76	1.882^{a}	5.451^{a}
	100	28.43^{b}	2.894	17.44	2.331^{b}	6.024^{b}
	150	29.64^{b}	2.880	17.03	2.368^{b}	6.339^{b}
	200	29.94^{b}	2.885	17.09	2.324^{b}	6.240^{b}
	F	30.00***	0.537	1.130	16.75***	19.39***

[a] numbers marked with the same letters are not significantly different; ***. **. * – probability level at 0.001; 0.01; 0.05 respectively

compared to MK system. No significant differences between objects MK- and MK+, and HK- and HK+ were found. For magnesium and calcium, it was, however, observed an antagonism, as documented by concentration decrease in response to increased supply of potassium. Effect of increasing nitrogen rates revealed for nitrogen, magnesium and calcium. In each case, the N rate of 100 kg N ha^{-1}, was high enough to increase significantly concentration of each of these nutrients. However, only nitrogen concentration responded considerably to the weather course in consecutive seasons.

Concentration of all determined nutrients was significantly modified by interaction of potassium fertilizing systems, which showed a significant year

Table 6

Nutrient sufficiency ranges in maize ear leaf at the stage of the beginning of anthesis, (g kg^{-1} DM)

Nutrients	Jones et al. 1990	Campbell, Plank 2000	Potarzycki 2010
N	26-36	28-40	21.3-33.3
P	2.2-4.0	2.5-5.0	2.3-3.5
K	18-45	18-30	18.8-25.1
Mg	4.3-10.0	2.5-8.0	4.1-6.7
Ca	2.7-3.4	1.5-6.0	2.8-3.6

-to-year variability. The predicted value of each nutrient has been evaluated by simple regression against grain yield. For nitrogen (N) it was significant, but the R^2 increased, when the tested set of data was limited only to dry years:

1. All years: GY = 1039N + 4187 for n = 12 , R^2 = 0.7738 and $P \le 0.001$
2. Years with drought: GY = 936.9N + 4311 for n = 8, R^2 = 0.88 and $P \le 0.001$.

Both equations implicitly indicate the importance of potassium in improvement the N management during the critical stage of yield formation by maize plant. Effect of nitrogen was also supported by higher concentration of magnesium, especially in years with drought:

$$GY = 29909Mg + 886 \text{ for } n = 8, R^2 = 0.59 \text{ and } P \le 0.01$$

The variability of phosphorus concentration in the ear leaf was affected by potassium fertilizing treatments, but showed a quite reverse trend to N and Mg. In this particular case, any increase of P concentration, especially in years with water shortage resulted in the grain yield (GY) decrease:

$$GY = -8642P + 9572 \text{ for } n = 12 , R^2 = 0.69 \text{ and } P \le 0.001.$$

The ameliorative effect of potassium fertilizing systems on K concentration was even more striking. Its significance reveals to provide considering just dry years:

$$GY = -3518K + 12644 \text{ for } n = 8, R^2 = 0.89 \text{ and } P \le 0.001.$$

These trends simple inform, that maize nutritional status at the beginning of maize flowering was significantly affected by water shortage. This trend clearly underlines a disturbance of nutrient management in maize during the period critical for components of yield formation (Jones et al. 1996). The growth disturbance resulted in the lower number of kernels per cob. In consequence, the size of the cob, which is considered as the physiological sink for carbohydrates, produced by maize during the grain filling period, was significantly decreased.

The calculated ratios of nitrogen to other nutrients showed a high response to all studied factors (Table 7). The impact of years was nutrient specific. The narrowest ratio, except N/P, was observed in 2006. Effect of potassium fertilizing systems was significant for each of the studied nutrient ratios, but the most pronounced was noted for N/Mg. In this case, an increase of potassium supply, resulted in the ratio increase. This trend corroborates the above presented hypothesis, concerning a close physiological relation between nitrogen and magnesium. The presented facts are in accordance with Grzebisz et al. (2010b) and Grzebisz et al. (2013), who underlined an importance of the improved management of magnesium for N economy of crop plants. Two of studied ratios, i.e., N/K and N/Ca were significantly affected by potassium fertilizing systems, but underlined a seasonal variability. In the first case, as presented in Figure 2, the N/K increase up to 2.17 resulted in the net yield of the grain increase. At this particular value, a

Table 7

A statistical evaluation of nutrient ratios in maize ear leaf at the stage of the beginning of anthesis

Main factor	Level of the factor	N/P	N/K	N/Mg	N/Ca
Years	2004	13.28[c]	2.440[c]	16.62[c]	5.584[b]
	2005	8.318[a]	1.702[b]	12.45[b]	5.623[b]
	2006	9.287[b]	0.994[a]	10.30[a]	3.020[a]
	F	117.9***	340.3***	92.21***	279.2***
Potassium fertilizing systems	MK-	10.47[ab]	1.718[ab]	10.83[a]	4.180[a]
	MK+	9.756[a]	1.796[b]	13.05[b]	4.862[b]
	HK-	10.84[b]	1.598[a]	13.01[b]	4.678[b]
	HK+	10.11[ab]	1.737[ab]	15.60[c]	5.249[c]
	F	2.791*	3.351*	25.42***	18.53***
Nitrogen rates	0	9.242[a]	1.431[a]	13.47	4.532
	100	10.27[b]	1.708[b]	12.72	4.787
	150	10.88[b]	1.854[b]	13.04	4.756
	200	10.78[b]	1.856[b]	13.27	4.892
	F	7.211***	19.48***	0.695	2.158

[a] numbers marked with the same letters are not significantly different; ***. **. * – probability level at 0.001; 0.01; 0.05 respectively

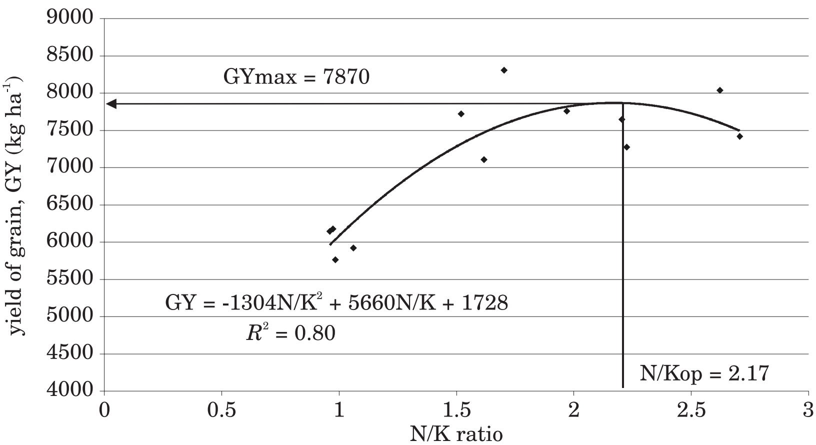

Fig. 2. Grain yield of maize as a function of N/K relationships in the ear leaf at anthesis

maximum yield of 7.87 t ha^{-1} was produced by maize. Further increase in this ratio resulted in grain yield decrease. This negative trend has revealed in the HK+ system of K management. The second case, referred to the N/Ca ratio, implicitly indicates on importance of N supply to plants during the period of growth impedance by stress:

$$GY = 580.2N/Ca + 4355 \text{ for } n = 12, R^2 = 0.80 \text{ and } P \leq 0.001.$$

Based on above presented data, it can be assumed, that any factor improving N economy of maize crop during the period of water stress, in turn increases yield of grain. In the studied case, effect of potassium fertilizing systems revealed via improvement in potassium, magnesium, calcium productivity. In has been observed the best growing conditions for maize revealed in treatments with broadened ratios of N/K, N/Mg, and N/Ca. These explanations have been fully corroborated by the detailed analysis of nutrient ratios on the harvested yield of grain (Table 8). The N/K ratios significantly affected yield of maize in all, except the HK+, systems. In this treatment, the applied K fertilizer resulted in the decrease of impact of this ratio on final yield of maize. The N/Mg ratio was significant only in the MK+ system, stressing on importance of magnesium for N management. The N/Ca ratio significantly influenced the grain yield, irrespectively on K fertilizing system. The highest production effect was related to the medium K fertile soil.

Table 8

Coefficients of correlation for grain yield versus nutrient relationship in the ear leaf, at the stage of the beginning of anthesis (n = 12)

Main factor	Level of the factor	N/P	N/K	N/Mg	N/Ca
Potassium fertilizing systems	MK-	0.227	0.780**	0.083	0.808***
	MK+	0.125	0.667**	0.700**	0.902***
	HK-	0.447	0.798***	0.414	0.689**
	HK+	0.065	0.494	0.390	0.718**

***-. **. * – probability level at 0.001; 0.01; 0.05 respectively

An evaluation of maize nutritional by the DRIS method

The DRIS method was applied to evaluate nutritional status of maize, taking into account all tested elements and ratios between them (Table 9). The Absolute Sum of Indices (ASI) is a good indicator of nutritional trends as imposed by increasing N rates on the background of potassium fertilizing systems. In general, the ASI significantly decreased, when maize was grown both on K fertile soil (HK main plot) and at the same time fertilized currently with potassium (K+ treatments). Consequently, the lowest ASI, amounting to 16.76 was noted for the most intensive K system, i.e., KH+.

Table 9

As assessment of maize nutritional status by the DRIS procedure at the stage of the beginning of anthesis

Potassium fertilizing systems	N rate, (kg ha^{-1})	Nutrient indices (DRIS)					Limiting nutrients	Absolute sum indices, (ASI)
		N	P	K	Mg	Ca		
MK-	0	-7.55	-7.10	-1.45	3.99	12.11	N ≥ P > K	32.20
	100	-1.95	-8.63	-6.04	5.50	11.13	P > K > N	32.25
	150	-2.66	-9.63	-9.25	8.10	13.45	P > K > N	43.09
	200	-2.01	-8.36	-7.87	6.40	11.85	P ≥ K > N	36.49
MK+	0	-3.01	-2.37	-1.83	-0.73	7.95	N > P > K > Mg	15.89
	100	-1.62	-2.75	-5.72	1.42	8.67	K > P > N	20.18
	150	0.59	-4.93	-6.75	2.13	8.96	K > P	23.36
	200	0.54	-4.00	-5.76	0.19	9.02	K > P	19.51
HK-	0	-6.72	0.13	1.48	-2.81	7.92	N > Mg	19.06
	100	-0.70	-7.69	-2.89	2.54	8.74	P > K > N	22.56
	150	0.96	-8.05	-4.31	1.32	10.08	P > K	24.72
	200	0.78	-7.46	-4.15	1.27	9.56	P > K	23.22
HK+	0	-0.04	-2.99	1.12	-5.6	7.51	P > Mg	17.26
	100	-1.30	-1.86	-1.95	-1.15	6.25	K ≥ P > N ≥ Mg	12.51
	150	1.18	-1.72	-3.25	-3.71	7.50	Mg ≥ K > P	17.36
	200	2.95	-3.48	-4.65	-1.83	7.01	K > P > Mg	19.92

The increasing N rates, except the KH+ plot, resulted in the ASI increase. However, it was not the most productive system. The main reason was to broaden N/K ratio.

The DRIS procedure allows also to indicate a nutrient(s) limiting yield of a given crop. In the studied case, the limiting nutrient was dependent on the potassium management system. It is obvious that nitrogen was the grain yield limited nutrient in the N fertilizing control. The exception was the HK+ plot, where N was in balance. In both treatments without fresh potassium application (K-), yield of grain was the most limited by phosphorus, followed by potassium. This place for phosphorus seems to be strange, in the light of its negative relationship with grain yield. This unexpected result is due to its low concentration in ear leaf in years with water shortages. It simply indicates on disturbance of P uptake by water stressed plants. The negative P impact on final grain yield was probably not due to its surplus but due to low capacity of maize cob to accumulate assimilates produced by maize during the grain filling period.

CONCLUSIONS

1. At the stage of 5^{th} of maize growth N/P concentration relationship can be used as the first predictor of final yield of maize.

2. Potassium concentration in maize at the stage of 5^{th} leaf impacts significantly maize nutritional status. The N/K ratio can be used for yield prediction only in years with temporary drought.

3. At the beginning of flowering nitrogen and magnesium concentration significantly depends on potassium management, resulting in the grain yield increase.

4. The ear leaf is a useful maize vegetative part to define an advanced symptoms of the crop nutritional status disturbance.

5. Any extension of N/K, N/Mg and N/Ca ratios due to effective potassium fertilizing system can be considered as the prerequisite of increasing yield of maize.

6. The DRIS is a useful procedure for evaluation of maize nutritional status at the beginning of flowering; in the studied case, corroborating the significant impact of potassium management on maize nutritional status.

7. The best growing conditions for maize are created on the medium K fertile soil, currently fertilized with potassium; these management system is a prerequisite of a high uptake K potential of maize.

REFERENCES

Campbell C.R., Plank C.O. 2000. *Reference sufficiency ranges field crops - corn.* In: C.R. Campbell (ed.) *Reference sufficiency ranges for plant analysis in the southern region of the United States.* Available online at: http://www.ncagr.gov/agronomi/saaesd/corn.htm (Verified 2010.12.30).

Elwali A.M.O., Gascho G.J., Summer ME.E. 1985. *Dris norms for 11 nutrients in corn leaves.* Agron. J., 77: 506-508.

Grzebisz W., Oertli J.J. 1994. *Evaluation of universal extractants for determining plant available potassium in intensively cultivated soils*. Comm. Plant Soil Anal., 24(11-12): 1295-1305.

Grzebisz W., Wrońska M., Diatta J.B., Dullin P. 2008*a*. *Effect of zinc application at early stages of maize growth on the patterns of nutrients and dry matter accumulation by canopy.* Part I. *Zinc uptake patterns and its redistribution among maize organs*. J. Elementol., 13(1): 17-28.

Grzebisz W., Wrońska M., Diatta J.B., Szczepaniak W. 2008*b*. *Effect of zinc application at early stages of maize growth on the patterns of nutrients and dry matter accumulation by canopy.* Part II. *Nitrogen uptake and dry matter accumulation patterns*. J. Elementol., 13(1): 29-39.

Grzebisz W., Baer A., Barłóg P., Szczepaniak W., Potarzycki J. 2010*a*. *Effect of nitrogen and potassium fertilizing systems on maize grain yield*. Fertilizers Fertilization. 40: 45-56.

Grzebisz W., Przygocka-Cyna K., Szczepaniak W., Diatta J.B., Potarzycki J. 2010*b*. *Magnesium as a nutritional tool of nitrogen efficient management - plant production and environment*. J. Elementol., 15(4):771-778.

Grzebisz W., Gransee A., Szczepaniak W., Diatta J.B. 2013. *The effects of potassium fertilization on water use-efficiency in crop plants*. J. Plant Nutr. Soil Sci., 176: 355-374.

Grzebisz W. 2013. *Crop response to magnesium fertilization as affected by nitrogen supply* Plant Soil, 368: 23-39.

Jones J.B., Eck H.V., Voss R. 1990. *Plant analysis as an aid in fertilizing corn and grain sorghum.* In: *Soil testing and plant analysis*. R.L. Westerman, (ed.) 3rd Soil Sci. Soc. Am. J., Book Ser. 3, Medison, WI: 521-527.

Jones R. J., Schreiber B. M.N., Roessler J.A. 1996. *Kernel sink capacity in maize: Genotypic and maternal regulation*. Crop Sci., 36: 301-306.

Kruczek A. 2005. *Phosphorus utilization from fertilizer and accumulation of mineral components in the initial stage of maize development*. Pol. J. Environ. Stud., 14(4): 467-475.

Mallarino A.P., Higashi S.L. 2009. *Assessment of potassium supply for corn by analysis of plant parts*. Soil Sci. Soc. Am. J., 73: 2177-2183.

Oosterhuis D.M., Loka D.A., Raper T.B. 2013. *A Potassium and stress alleviation: Physiological functions and management of cotton*. J. Plant Nutr. Soil Sci., 176: 331-343.

Otegui M., Bonhomme R. 1998. *Grain yield components in maize.* I. *Ear growth and kernel set*. Field Crops Res., 56: 247-256.

Parrent L.E. 2011. *Diagnosis oft he nutrient compostional space of fruit crops*. Rev. Bras. Frutic., Jaboticabal – SP, 3391: 321-334.

Potarzycki J. 2010. *Influence of balanced fertilization on nutritional status of maize at anthesis*. Fertilizers Fertilization, 39: 90-108.

Potarzycki J. 2011. *Effect of magnesium or zinc suplementation at the background of nitrogen rate on nitrogen management by maize canopy cultivated in monoculture.* Plant Soil Environ., 57: 19-25.

Schulte E.E., Kelling K.A. 1991. *Analysis: a diagnostic tool.* University of Wisconsin-Madison, NCH-46 Crop Fertilization, RR 4/91. Available online at: http://ces.purdue.edu/extmedia/NCH/NCH-46.html (Verified 2012.05. 25).

Soltanpour P.N., Malakouti M.J., Ronaghi A. 1995. *Comparison of diagnosis and recommendation integrated system and nutrient sufficiency range for corn*. Soil Sci. Soc. Am. J. 59: 133-139.

Subedi K., Ma B. 2005. *Nitrogen uptake and partitioning in stay-green and leafy maize hybrids.* Crops Sci., 45: 740-747.

Walworth J.L., Summer M.E. 1987. *The Diagnosis and recommendation integrated system (DRIS)*. Adv. Soil Sci., 6: 149-188.