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Magnesium content in the leaves of winter wheat in a long-term fertilization experiment

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ABSTRACT

Long-term experiments facilitate the observations of changes in soil properties affected by agricultural activity as well as the reactions of crops to those properties. The aim of the study was the assessment of the relationship between the soil pH as well as contents of organic carbon, total nitrogen, available forms of phosphorus, potassium (K_{av}), magnesium (Mg_{av}) and the magnesium content in flag leaves (Mg_{fl}) in winter wheat. There was also determined the correlations between the Mg_{fl} content and the nitrogen (N_{fl}), phosphorus, potassium (K_{fl}) and calcium (Ca_{fl}) contents in those leaves. The Mg_{fl} content was at-the-highest-level linearly positively correlated with soil pH and its richness in Mg_{av}. The dependence of the Mg_{fl} content on soil properties and the wheat leaves chemical composition was best described by polynomial equations of the 2nd degree, except for the K_{av} and K_{fl} contents. The Mg_{fl} content depending on the Mg_{av} content × soil pH and Mg_{av} × K_{av} interaction. The winter wheat containing more N_{fl} and Ca_{fl} and less K_{fl}, accumulated more Mg_{fl}.

Keywords: *Triticum aestivum*; available macroelements; field experiment; cereales

Magnesium (Mg) is a very important element for soil properties and plant growth (Staugaitis and Rutkauskienė 2010). It plays an essential role not only in photosynthesis but also in other plant physiological processes. Marschner (2012) suggested that the only about 20% of the amount of Mg in the plant is connected to chlorophyll and the other amount occurs in a mobile form. The Mg is indispensable for the activity of many enzymes (Cakmak and Kirkby 2008), production and distribution of organic compounds (Ding et al. 2006), resistance and tolerance of plants to stress environmental factors (Mengutay et al. 2013).

The source of Mg in soil are mostly rock material containing various silicates and fertilizers. The mobility of Mg in soil and availability to plants are determined not only by its amount but also soil properties as pH, concentration of other ions, moisture, temperature and agronomic management practices (Gransee and Führs 2013).

The chemical composition of crops depends on environmental conditions and agronomic practices, including fertilization (Sager and Hoesch 2005, Woźniak and Makarski 2012). Long-term fertilization results in big changes in e.g. content of the organic carbon (C_{org}) and total nitrogen (N_{tot}) (Bhattacharyya et al. 2010), macro- and micronutrients (Madaras and Lipavský 2009, Rutkowska et al. 2014), soil reaction (Debreczeni and Kismanyoky 2005), physical properties (Suwara and Szulc 2011).

The present research has assumed that more than 60 years of organic and mineral fertilization differentiated not only the available forms of magnesium (Mg_{av}) content, but also other soil properties affecting the uptake of macronutrients by winter wheat. The aim of the study has been to determine the effect of some soil properties developed by the application of organic and mineral fertilizers in a long-term experiment (pH value and C_{org}, N_{tot}, available forms of phosphorus (P_{av}), potassium (K_{av}), Mg_{av} contents on the magnesium content in flag leaves (Mg_{fl}) in winter wheat cv. Batuta. There was also assessed the relationship between the Mg_{fl} and the nitrogen (N_{fl}), phosphorus (P_{fl}), potassium (K_{fl}) and calcium (Ca_{fl}) contents in leaves in those soil conditions.

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MATERIAL AND METHODS

Field experiment. The material for present research was made up by the samples of soil and plant material: the leaves of winter wheat cv. Batuta sampled over 2009–2011 from 56 objects of long-term fertilization experiment located at the Experiment Station at Mochełek (53°12'N, 17°51'E, 98.5 m a.s.l.), Poland. The experiment was set up in 1948 in Albic Luvisol (IUSS Working Group WRB 2014) and it is located in the arid region. The annual precipitation is about 450 mm. The source of variation in the soil properties is its natural variation within the experimental field as well as differentiated fertilization (Jaskulska et al. 2014). Basic fractions of the soil are: sand 77.8% (68–84), silt 20% (14–29) and clay 2.3 (2.0–3.5). From the beginning to 2011 fertilization was varied. There was applied per year: 25–110 kg N/ha (ammonium sulphate), 17–46 kg P/ha (superphosphate), 19–120 kg K/ha (potassium chloride), 12–20 kg Mg/ha (magnesium sulphate), 110–640 kg Ca/ha and farmyard manure (30–50 t/ha), straw (5 t/ha) once in the crop rotation.

Soil sampling and analysis. Soil was sampled from the 0–20 cm layer of each object using the Egner stick in the stage of winter wheat development 37–39 BBCH. The soil was air-dried, mixed and sieved through the 2 mm sieve. The soil pH value was determined in 1 mol/L KCl – 1:2.5 soil:solution suspension (phameter Schott Gerate CG 840, Hofheim, Germany). The C_{org} and N_{tot} contents were recorded using Vario MAX CN – Elementar, Hanau, Germany. The P_{av} and K_{av} were extracted according to the Egner-Riehm method (0.02 mol/L hydrochloric acid and 0.04 mol/L calcium lactate, pH 3.6, soil:solution ratio 1:50) and Mg_{av} – with the Schachtschabel method (0.025 mol/L $CaCl_2$, soil:solution ratio 1:10). The P_{av} content was assayed using the spectrophotometer (Genesis 6, Madison, USA), K_{av} and Mg_{av} applying the atomic absorption spectrometry AAS (Philips 9100, Cambridge, UK).

Chemical composition of winter wheat leaves. At winter wheat stage 39–41 BBCH from each experimental object 100 flag leaves were randomly sampled. The plant material was air-dried, homogenized, and then dried at the temperature of 105°C and mineralized in the concentrated sulphuric (VI) acid (*d* = 1.84 g/mL) with catalyst $CuSO_4 \cdot 5\,H_2O$ and K_2SO_4 added. The N_{fl} content determined with the Kjeldahl method applying Kjel-Foss Automatic 16210 A/S N. Foss Electric (Hillerod, Denmark). Plant material mineralization to determine the P_{fl}, K_{fl}, Mg_{fl} and Ca_{fl} contents was performed using concentrated H_2SO_4 in the presence of H_2O_2. The P_{fl} was determined with the spectrophotometric method using the SPEKOL 10 Carl Zeiss Jena (Jena, Germany). The K_{fl}, Mg_{fl} and Ca_{fl} contents were defined with the flame atomic emission spectrometry method (FAES) using the atomic absorption spectrometer (SpectrAA200 Varian, USA).

Data analysis. The results of the analyses of soil properties and the chemical composition of flag leaves in winter wheat verified statistically. There were calculated the basic descriptive statistics, standard deviation and standard error, as well as the coefficient of variation of those features. There was made multivariate analysis of soil properties with the principal component analysis method. The relationship between the Mg_{fl} content and the other components in wheat leaves as well as respective soil properties was determined with the Pearson coefficient of simple correlation ($P < 0.05$). Besides there was made the analysis of polynomial regression with one or many independent variables – soil properties and chemical composition of winter wheat leaves and one dependent variable – Mg_{fl}. Non-significant variables were eliminated at $P < 0.05$. Statistical analyses were made applying Statistica 7.0 software (StatSoft Inc, Tulsa, USA).

RESULTS AND DISCUSSION

The principal component analysis method indicate that in long-term fertilization experiment the P_{av} and Mg_{av} content correlated strongly positively with pH of soil (Figure 1). Descriptive statistics of the soil properties are given in Table 1.

In the present research Mg_{fl} content was correlated with the Mg_{av} and P_{av} contents and soil pH value (Table 1). In the uptake of nutrients by plants occurs the ionic antagonism, e.g. K can limit the uptake of Mg. In our study the coefficients of simple correlation were $r = -0.28$, for the relationship between the K_{av} and Mg_{fl} contents as well as $r = -0.34$, for the K_{fl} and Mg_{fl}.

Polynomial of the 2nd degree the best described the dependence of the Mg_{fl} content on respective soil properties as well as on the other nutrients contents in leaves. An exception were of negative linear dependencies of the Mg_{fl} content on the

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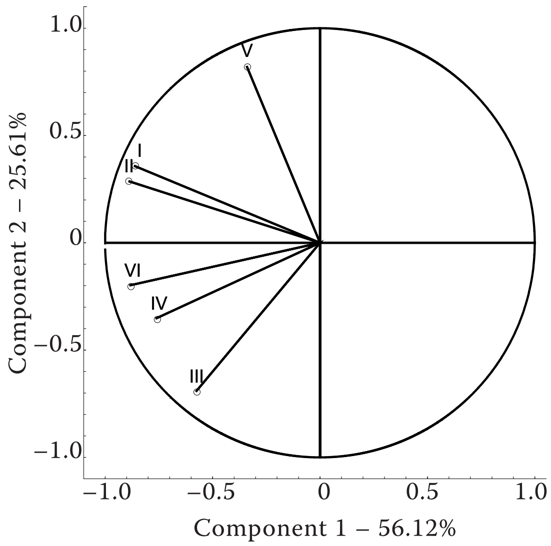

Figure 1. Soil properties: I – organic carbon (g/kg soil); II – total nitrogen (g/kg soil); III – pH; IV – available phosphorus (mg/kg soil); V – available potassium (mg/kg soil); VI – available magnesium (mg/kg soil) in the system of the first two principal components

K_{av} and K_{fl} contents (Table 2). The analysis of quadratic functions describing the dependence of the Mg_{fl} content on respective soil properties points to an increase in the that nutrient content in leaves together with an increasing value of a given soil property. Many authors point to a favourable effect of pH value and soil fertility on the uptake of nutrients by plants (Sultana et al. 2009, Saha et al. 2014).

The environmental conditions and agronomic practices affect the plants uptake not only one nutrient but all of them. For that reason the content of a given nutrient in the plant biomass remains in relationship with others (Tůma et al. 2004). In our long-term fertilization experiment it was found that the wheat contained the more Mg_{fl}, the more N_{fl} and Ca_{fl} they accumulated. Those dependencies were best described by equations of the 2nd degree. The Mg_{fl} content was decreasing, however, linearly together with an increase in the K_{fl} content and curvilinearly with an increase in the P_{fl} content. The literature well documents an unfavourable effect of K on Mg uptake (Swift et al. 2007). In contrast, the effect of P on Mg content in plant biomass is ambiguous. Wierzbowska and Bowszys (2008) in a pot experiment showed that the effect of P fertilization on the accumulation of Mg in wheat tissues depending on the rate of the nutrient and the plant organ. Increasing P rates decreased the Mg in the grain and in the subflag leaf. The Mg_{fl} content was limited, however, only by a very high P rate.

The multiple regression analysis shows that the accumulation of Mg_{fl} was determined not only by the content of available forms of that nutrient in soil but also interactively by its other properties. The increase in the Mg_{fl} content in winter wheat depended on a simultaneous curvilinear increase in the Mg_{av} and decreasing K_{av} contents in soil – $R^2 = 0.763$ (Figure 2), as well as increase in soil pH value – $R^2 = 0.642$ (Figure 3). A lower amount of K_{av} in soil surely facilitate a greater uptake of

Table 1. Statistic of soil properties and chemical composition of winter wheat flag leaves (fl)

	Property		Value			SE	*V*	*r*
			min	max	mean			
Soil properties	pH		4.75	6.75	5.74	0.16	9.2	0.66
	organic carbon	(g/kg soil)	4.84	9.39	6.81	0.02	17.7	ns
	total nitrogen	(g/kg soil)	0.49	1.18	0.77	0.07	19.0	ns
	available phosphorus	(mg/kg soil)	58.0	136.9	95.6	2.54	19.8	0.49
	available potassium	(mg/kg soil)	56.0	145.3	98.8	2.92	22.1	−0.28
	available magnesium	(mg/kg soil)	13.5	39.0	22.2	0.78	26.4	0.66
Nutrients contents in flag leaves	N_{fl}	(g/kg DM)	33.2	42.2	37.6	0.28	5.5	0.58
	P_{fl}	(g/kg DM)	2.79	3.92	3.24	0.04	9.4	ns
	K_{fl}	(g/kg DM)	14.6	22.1	18.7	0.20	8.0	−0.34
	Ca_{fl}	(g/kg DM)	4.86	10.01	6.78	0.16	17.9	0.53
	Mg_{fl}	(g/kg DM)	1.24	2.33	1.65	0.03	14.0	1.00

SE – standard error of the mean; *V* – coefficient of variation (%); *r* – coefficient of simple correlation between the soil properties, chemical composition of winter wheat and Mg_{fl} content; ns – non-significant; DM – dry matter

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Table 2. Dependence of magnesium content in winter wheat on soil properties and nutrients contents in flag leaves (fl)

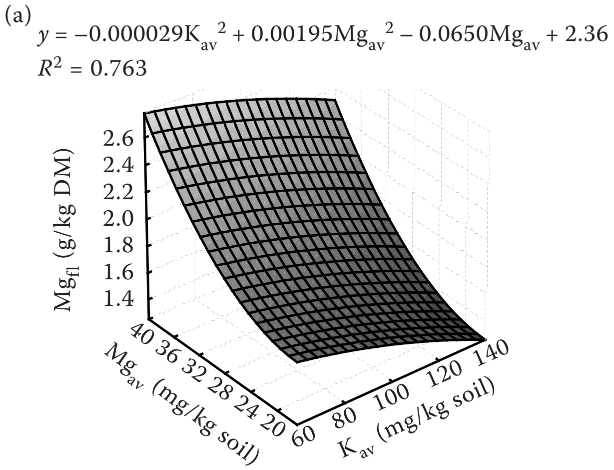
		Regression equation	Coefficient of determination
Soil properties	pH	$y = 0.2677x^2 - 2.7503x + 8.55$	$R^2 = 0.507$
	organic carbon	$y = 0.0520x^2 - 0.6867x + 3.84$	$R^2 = 0.124$
	total nitrogen	$y = 0.2727x^2 + 1.49$	$R^2 = 0.076$
	available phosphorus	$y = 0.000032x^2 + 1.35$	$R^2 = 0.258$
	available potassium	$y = -0.0030x + 1.94$	$R^2 = 0.078$
	available magnesium	$y = 0.00055x^2 + 1.36$	$R^2 = 0.485$
Nutrients contents in flag leaves	N_{fl}	$y = 0.0109x^2 - 0.7505x + 14.43$	$R^2 = 0.397$
	P_{fl}	$y = -0.6281x^2 + 4.0096x - 4.69$	$R^2 = 0.112$
	K_{fl}	$y = -0.0518x + 2.62$	$R^2 = 0.116$
	Ca_{fl}	$y = 0.0391x^2 - 0.4494x + 2.84$	$R^2 = 0.400$

Mg, which is seen from earlier wheat nutrition research (Ohno and Grunes 1985).

The interactive effect of nutrients was also identified in the chemical composition of flag leaves in winter wheat. They accumulated more Mg_{fl} when simultaneously contained more N_{fl} and less K_{fl} (Figure 4). Drawing on the results of many research, one can claim that N fertilization strongly affects not only the content of that nutrient in plant biomass but also others, including Mg (Wilczewski 2014). The K content in plants is, in general, negatively correlated with the content of Mg (Ding and Xu 2011). Moore et al. (2014) recorded a negative correlation between the K_{av} content in soil and the Mg content in corn tissues.

In conclusion, the dependence of Mg_{fl} on respective soil properties is best described by the polynomial equation of the 2nd degree. The Mg_{fl} content was

(a)



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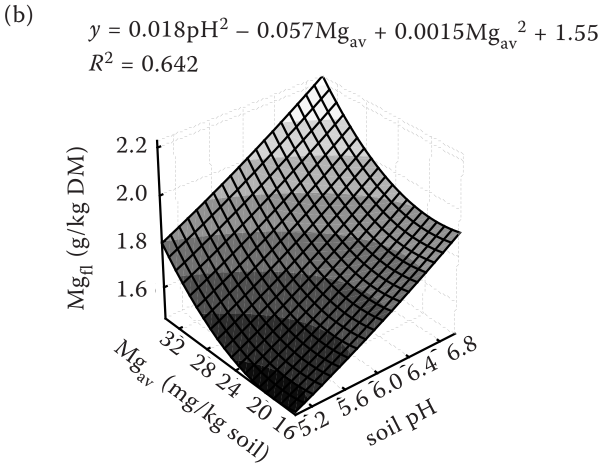

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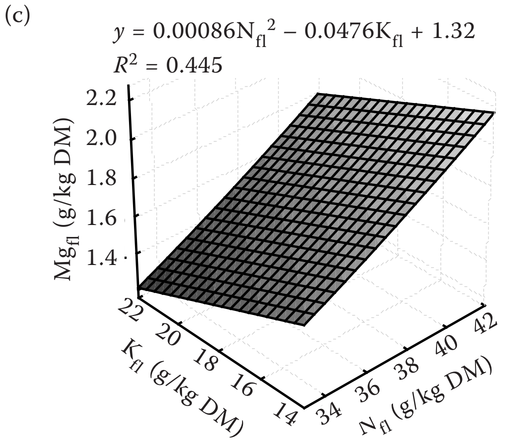

Figure 2. Magnesium content in flag leaves (Mg_{fl}) in winter wheat depending on (a) available potassium (K_{av}) and available magensium (Mg_{av}), (b) soil pH and Mg_{av} and (c) interation nitrogen in flag leaves (N_{fl}) and potassium in flag leaves (K_{fl}) contents; DM – dry matter

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increasing mostly together with the alkalization of soil reaction (R^2 = 0.507), an increase in the Mg_{av} (R^2 = 0.485) and P_{av} contents (R^2 = 0.258). However, an increase in the richness of soil in K_{av} linearly limited its accumulation in leaves (R^2 = 0.078). The interactive effect of soil properties on the accumulation of Mg_{fl} was stronger. An increase in soil pH was increasing (R^2 = 0.642) and soil richness in K_{av} – decreasing (R^2 = 0.763) a favourable effect of Mg_{av} on Mg_{fl} content in wheat. In such soil conditions the wheat plants containing more N_{fl} and Ca_{fl} and less K_{fl} accumulated more Mg_{fl}.

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