

## 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 2<sup>nd</sup> degree, except for the  $K_{av}$  and  $K_{fl}$  contents. The  $Mg_{fl}$  content depending on the  $Mg_{av}$  content  $\times$  soil pH and  $Mg_{av} \times K_{av}$  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 Führes 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.

## 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 Kjeld-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 2<sup>nd</sup> 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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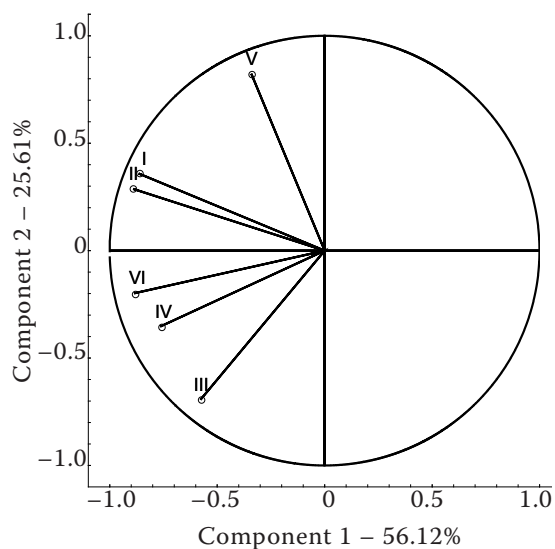


Figure 1. Soil properties: I – organic carbon (g/kg soil); II – total nitrogen (g/kg soil); III – pH; IV – available phosphorus (mg/kg soil); V – available potassium (mg/kg soil); VI – available magnesium (mg/kg soil) in the system of the first two principal components

$K_{av}$  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 2<sup>nd</sup> 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	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	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	13.5	39.0	22.2	0.78	26.4	0.66
Nutrients contents in flag leaves	$N_{fl}$	33.2	42.2	37.6	0.28	5.5	0.58
	$P_{fl}$	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
	$Ca_{fl}$	4.86	10.01	6.78	0.16	17.9	0.53
	$Mg_{fl}$	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

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).

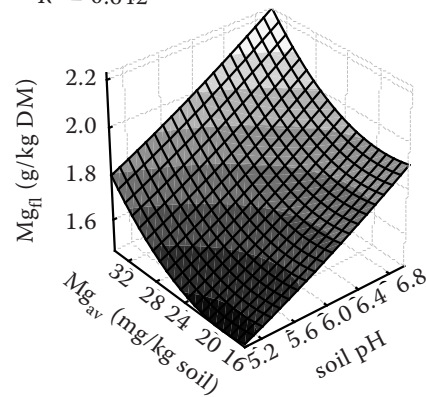
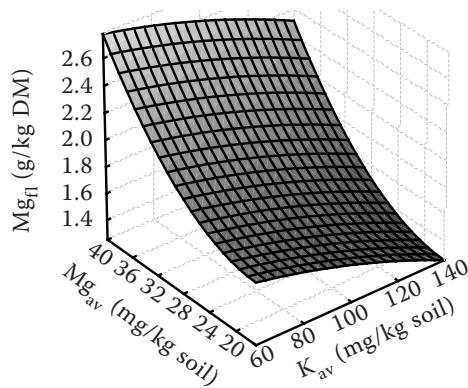
The interactive effect of nutrients was also identified in the chemical composition of flag leaves in winter wheat. They accumulated more  $Mg_{fl}$  when simultaneously contained more  $N_{fl}$  and less  $K_{fl}$  (Figure 4). Drawing on the results of many research, one can claim that N fertilization 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 2<sup>nd</sup> degree. The  $Mg_{fl}$  content was

(a)  $y = -0.000029K_{av}^2 + 0.00195Mg_{av}^2 - 0.0650Mg_{av} + 2.36$   
 $R^2 = 0.763$

(b)  $y = 0.018pH^2 - 0.057Mg_{av} + 0.0015Mg_{av}^2 + 1.55$   
 $R^2 = 0.642$



(c)  $y = 0.00086N_{fl}^2 - 0.0476K_{fl} + 1.32$   
 $R^2 = 0.445$

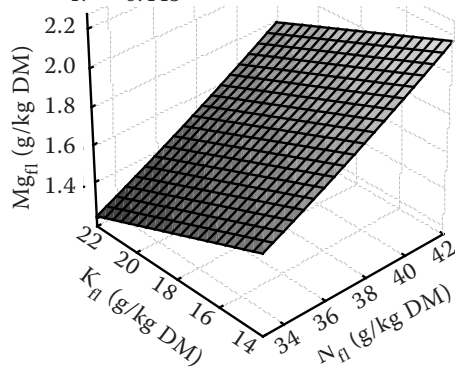


Figure 2. Magnesium content in flag leaves ( $Mg_{fl}$ ) in winter wheat depending on (a) available potassium ( $K_{av}$ ) and available magnesium ( $Mg_{av}$ ), (b) soil pH and  $Mg_{av}$  and (c) interaction nitrogen in flag leaves ( $N_{fl}$ ) and potassium in flag leaves ( $K_{fl}$ ) contents; DM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