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Magnesium management in the soil-crop system – a crop rotation approach

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ABSTRACT

Magnesium (Mg) budgeting was conducted on a production farm at Górzno, Poland during the 2004–2007 growing seasons for 15 crop sequences: nine with oil-seed rape (OR) and six with maize grown for grain or silage (SM) as dominant crops. The impact of cropping sequences (CS) on Mg management was evaluated using two methods: soil surface balance, and soil system balance. The Mg yield output ranged from 4.5–17 kg Mg/ha, but including harvest residues from 8.9–22.9 kg Mg/ha. The average quantity of external Mg, required to balance its yield output reached 5.8 kg/ha in the OR-CS and 10.4 kg/ha in the SM-CS. The net Mg input, through mineral fertilizer, farmyard manure, seeds, and precipitation ranged from 1.3–17.3. The negative value of the total gross Mg balance (–10 kg Mg/ha) implicitly indicates on its soil pool as the key source for the growing crops. Plants grown in the OR-CS compared to the SM-CS used both external and soil sources of Mg more efficiently. Plants grown in cropping sequences dominated with maize, with higher needs for Mg, showed strong uptake capability in exploitation of soil Mg available pool.

Keywords: nutrient; *Zea mays*; oilseed rape; soil magnesium balance

Magnesium (Mg) due to its specific functions in living organism is a key nutrient in crop production (Zatloukalová et al. 2011). Its bio-physiological functions are well recognized, including a unique action of chlorophyll molecules in CO_2 fixation and in dry matter partition between crop organs (Shaul 2002). In spite of the extended knowledge concerning the bio-physical background of plant growth, there is a deep gap about crop plants' requirements for magnesium (Grzebisz et al. 2010). Nutrient balance is considered as a simple diagnostic procedure, evaluating a current status of crop nutrient management. Two main approaches are used to assess trends in a nutrient balance during a fixed period, i.e. a single vegetative season, or a cropping sequence. The soil surface balance (SSuB) relies on a net balance of an external input and output of a given nutrient. The soil system balance (SSyB) procedure relies on both external and internal (soil) resources (Oenema et al. 2003).

The SSyB is seldom used by both researchers and advisers, because it needs data about the content of soil available Mg (Mg_{sav}) at the beginning and the end of the growing season. This diagnostic disadvantage can be overcome by using an extraction solution, for example, based on 0.01 mol/L $CaCl_2$ (Houba et al. 2000) and increasing the depth of soil sampling. In typical Luvisols, mainly cropped with cereals, the soil is exploited with Mg_{sav} to the depth of 0.6–0.8 m (Piechota et al. 2000).

The minor objective of the study was to compare a potential diagnostic value of two methods of Mg balance (SSuB and SSyB) based on two distinct groups of cropping sequences. The major objective of this study was to compare the impact of cropping sequence with oilseed rape or maize as dominant crops on Mg management in the soil-crop system.

MATERIAL AND METHODS

This study was carried out at the Górzno farm, located in the central-western Poland (51°74'N, 17°83'E). The farm has 400 ha of agricultural land,

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dominated by arable soils originating from sand or loamy sand. According to the FAO/WRB classification system, all studied soils are classified as typical Luvisols. The three predominant crops are winter oilseed rape (OR), silage/grain maize (SM) and winter wheat (WW). The acronyms presented in Table 1 indicate the intensity of the cropping sequence, as related to the frequency of oilseed rape and/or maize cultivation. The average annual precipitation is 500 mm, and the mean air temperature is 7.8°C. Yield of cereals and oilseed rape was measured with a combine harvester and maize by silage harvester. To facilitate comparison, yields of all crops were converted into Cereals' Units (CUs, Brankatschk and Finkbeiner 2014).

The composite soil samples were collected from each field twice a year, at the beginning of each spring season for winter crops and prior to planting the spring crops (acronym: spring) and immediately after harvest and prior to planting the winter crops (autumn). The one composite sample represents an area of 4.0 ha, and the total number of samples was adjusted to field size (Table 1). Soil samples were taken at three depths: 0–30, 31–60 and 61–90 cm. The soil available magnesium was determined in 0.01 mol/L $CaCl_2$ solution to soil ratio of 5:1 (Houba et al. 2000).

Total magnesium concentrations in plant tissues were measured by harvesting plants from 1.0 m^2 area at maturity. The harvested plant sample (grain, straw, harvest residues, or total biomass) was dried (65°C). Next, the dried plant material was incinerated in a muffle furnace at 550°C then releasing the Mg into solution using 33% HNO_3. Magnesium concentration was measured by atomic-absorption spectrometry (SpectrAA 250 Plus, Varian, Santa Clara, USA). Magnesium content in plant tissues was calculated based on its concentration in a particular crop part and its biomass.

Components of the magnesium budget included (kg Mg/ha): (1) magnesium input (Mg_I) – sources: (a) magnesium fertilizer (Mg_f); (b) farmyard manure (Mg_{fym}); (c) seeds (Mg_{se}) and precipitation (Mg_{prec}). (2) magnesium output (Mg_O) – content in: (a) the

Table 1. Basic characteristics of magnesium (Mg) balance components

Field	Cropping sequence	Field size (ha)	Y-CUs (kg/ha)	Mg_I	Mg_{sav-s}	Mg_{TI}	Mg_Y	Mg_{res}	Mg_O	Mg_{sav-A}	Mg_{TO}	UMgP-I	UMgP-TI
				(kg Mg/ha)								(kg CUs/kg Mg)	
OR1	WR-WR-OR^{m}	14.8	5.330^{ab}	4.1	134^{ab}	138^{ab}	6.8	5.8	12.6	142	155	2.923^{abc}	39^{ab}
OR2	WW-WR-OR^{m}	7.0	4.160^{ab}	5.4	177^{ab}	182^{ab}	4.8	5.0	9.7	210	220	993^{a}	23^{a}
OR3	WW-OR^{m}-WW	17.2	5.813^{ab}	4.0	102^{a}	106^{a}	6.4	4.8	11.2	93	105	2.146^{ab}	55^{b}
OR4	WW-OR^{m}-WW	15.5	5.173^{ab}	4.7	120^{ab}	124^{ab}	6.3	4.9	11.2	131	142	1.226^{a}	42^{ab}
OR5	WW-OR^{m}-WW	13.7	6.420^{ab}	5.0	141^{ab}	146^{ab}	7.1	15.8	22.9	132	155	1.495^{ab}	45^{ab}
OR6	WW-OR^{m}-WW	10.3	5.313^{ab}	4.7	157^{ab}	162^{ab}	6.7	4.7	11.4	127	139	1.247^{a}	33^{ab}
OR7	WW-OR^{m}-WW	9.5	4.133^{ab}	4.7	166^{ab}	171^{ab}	4.5	4.4	8.9	182	191	960^{a}	26^{a}
OR8	WW-OR^{m}-WW	40.8	5.053^{ab}	5.4	174^{ab}	179^{ab}	5.7	4.5	10.2	133	143	1.201^{a}	29^{ab}
OR9	OR^{m}-WW-OR^{m}	46.6	4.380^{ab}	7.3	163^{ab}	170^{ab}	5.8	4.7	10.5	174	184	775^{a}	27^{ab}
SM1	WR^{f}-SB-SM^{f}	55.2	5.944^{ab}	15.3	165^{ab}	180^{ab}	12.8	4.1	16.9	184	201	446^{bc}	34^{ab}
SM2	SM-WW-OSR	13.4	4.717^{ab}	1.3	163^{ab}	165^{ab}	6.3	4.6	10.9	136	146	3.520^{a}	29^{ab}
SM3	SM-WW-OSR	14.9	4.820^{ab}	1.3	155^{ab}	156^{ab}	11.5	3.9	15.4	157	173	3.627^{a}	33^{ab}
SM4	SM-SM-SB	14.8	7.288^{b}	1.3	205^{b}	206^{b}	14.4	4.0	18.3	164	182	5.422^{c}	35^{ab}
SM5	SM-SM^{f}-SM^{f}	26.2	3.127^{a}	17.3	143^{ab}	160^{ab}	16.1	0.0	16.1	152	168	700^{a}	20^{a}
SM6	SM-SM-SM^{f}	31.6	4.317^{ab}	9.3	111^{ab}	120^{ab}	17.0	1.8	18.9	190	209	1.810^{ab}	36^{ab}
Mean		22.6	5.066	6.1	151.7	157.8	8.8	4.9	13.7	154	168	1.901	34
SD		15.2	1.032	4.7	27.1	26.7	4.3	3.3	4.1	31	31	1.392	9
CV (%)		67	20	77	18	17	49	69	30	20	19	73	27

[a]numbers marked with the same letter are not significantly different; m, f – magnesium in mineral fertilizers or in farmyard manure. OR – winter oil-seed rape; SM – silage/grain maize; WW – winter wheat; WR – winter rape; SB – spring barley; Y-CUs – yeld of cereals units; Mg_I – magnesium input; Mg_{sav} – soil available Mg; Mg_{TI} – total input; Mg_Y – main yield; Mg_{res} – crop residues; Mg_O – magnesium output

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main yield (Mg_Y): grain (cereals, maize), seeds (oilseed rape), whole biomass (silage maize); (b) crop residues (Mg_{res}): straw, harvest residues. (3) soil available Mg, measured directly: (a) before the spring season for a particular crop start – (Mg_{sav-S}, kg Mg/ha); (b) immediately after a particular crop harvest – (Mg_{sav-A}, kg Mg/ha).

The magnesium content in the composite components of its budget was calculated as:

$$Mg_I = \Sigma(Mg_f + Mg_{fym} + Mg_{se} + Mg_{prec}) \quad (1)$$

$$Mg_O = \Sigma(Mg_Y + Mg_{res}) \quad (2)$$

$$Mg_{TI} = \Sigma(Mg_{sav-S} + Mg_I) \quad (3)$$

$$Mg_{TO} = \Sigma(Mg_{sav-A} + Mg_O) \quad (4)$$

Where: Mg_{TI} and Mg_{TO} – total input and output of magnesium in the system, composed as a sum of its external and soil pools.

Indicators of magnesium balance were calculated based on equations included in Table 2.

The experimentally obtained data were statistically analysed using Statistica 12® (StatSoft Inc., Tulsa, USA). The differences between treatments were evaluated with the Tukey's test. The simple regression was used to define the best set of variables for a given characteristic.

RESULTS AND DISCUSSION

Yield is the main base of any cropping sequence (CS) evaluation (Table 1). The highest yield was recorded in the SM4 field, composed during the study of grain maize and spring barley, but the lowest in the field with silage maize monoculture (SM5). Yields above the average were recorded mostly in fields with oilseed rape. The year-to-year variability in yield harvested in OR cropping sequences was low (15%) compared to the SM ones (28%).

Magnesium was not added to three fields. In nine, it was a supplement of solid fertilizers (Table 1). In three fields, mainly maize, it was incorporated in manure. As a result, Mg input ranged broadly from 1.3–17.3 kg/ha. The dominant source of Mg for growing plants was its soil available resources, which on average contributed to 96% of its total input to the soil-crop system. Consequently, the *CV* varied from 77% for the external Mg sources to 17% for its soil available pool.

The amount of Mg in the yield and crop residues was affected by the dominant crop in the given cropping sequence. In the OR-CSs, the average quantity of Mg_Y reached 6.0 kg/ha, whereas in the SM ones, it was more than twice as high (13.1 kg/ha). The mean quantity of Mg in the crop residues showed a reverse trend, amounting to 6.1 and 3.1 kg/ha for OR and SM fields, respectively. The average Mg_{sav-A} content contributed to 91.7% of the total Mg output (Mg_{TO}).

The indices of the unit Mg productivity (UMgP) significantly responded to the source of Mg and the type of cropping sequence. The $UMgP_I$ index based on the Mg_I was extremely variable, ranging from 700 in the SM1 to 5.422 CUs/kg Mg in the SM4. In the first field, manure was the key source

Table 2. Indicators of magnesium balance for soil surface balance and soil system balance

Indicator	Equation	Dimension
Soil surface balance		
Net magnesium balance	$NMgB = Mg_I - Mg_Y$	(kg Mg/ha)
Net magnesium efficiency	$NMgE = (Mg_Y/Mg_I) \times 100$	(%)
Total magnesium balance	$TMgB = Mg_I - Mg_O$	(kg Mg/ha)
Total magnesium efficiency	$TMgE = (Mg_O/Mg_I) \times 100$	(%)
Soil system balance		
Total net magnesium balance	$TNMgB = Mg_{TI} - Mg_Y$	(kg Mg/ha)
Total net magnesium efficiency	$TNMgE = (Mg_{TI}/Mg_Y) \times 100$	(%)
Total gross magnesium balance	$TGMgB = Mg_{TI} - Mg_{TO}$	(kg Mg/ha)
Total gross magnesium efficiency	$TGMgE = (Mg_{TO}/Mg_{TI}) \times 100$	(%)

Mg_I – magnesium input; Mg_Y – main yield; Mg_O – magnesium output; Mg_{TI} – total input; Mg_{TO} – total output

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of externally applied Mg, whereas in the second one, it was only rainfall and seeds. The significant relationship between the $UMgP_I$ and yield was obtained in the OR-CS and in the SM-CS one, provided the SM1 field was excluded:

$$\text{OR: } Y = 0.0013\ UMgP_I^2 + 5.412\ UMgP_I + 514.1 \quad \text{for } n = 9;\ R^2 = 0.75;\ P \leq 0.001 \tag{5}$$

$$\text{SM: } Y = 0.787\ UMgP_I + 2480 \quad \text{for } n = 5;\ R^2 = 0.89 \text{ and } P \leq 0.01 \tag{6}$$

The pattern of the UMgP index for the OR-CSs followed the quadrate regression model with the optimum at 2.082 kg CUs/kg Mg_I and the respective maximum yield of 6.15 kg CUs/ha. Among the studied cropping sequences, the only OR5 supplied with 5.0 kg Mg/ha fulfilled this pattern, and yielded at the level of 6.420 kg/ha. It indicates oilseed rape as the magnesium sensitive crop (Szczepaniak et al. 2015). In some fields with maize, the UMgP indices were incredibly high. Much more realistic pattern of Mg productivity in the soil-crop system was achieved based on its total input. The average $UMgP_{TI}$ index amounted to 34 kg CUs/kg Mg, being 56-time lower compared to the respective UMg_I. It showed also much lesser variability, ranging from 20 in the SM5 to 44.7 CUs/kg Mg in the OR5. The relationship between $UMgP_{TI}$ and yield depended on the cropping sequences as well, reaching the quadrate for the OR and linear model for SM-CSs, respectively (Figure 1). The conducted calculations clearly showed that both types of cropping sequences differ in exploitation of soil Mg resources. The oilseed rape cropping sequence showed much higher productivity of both external and internal sources of Mg compared to SM-CS one.

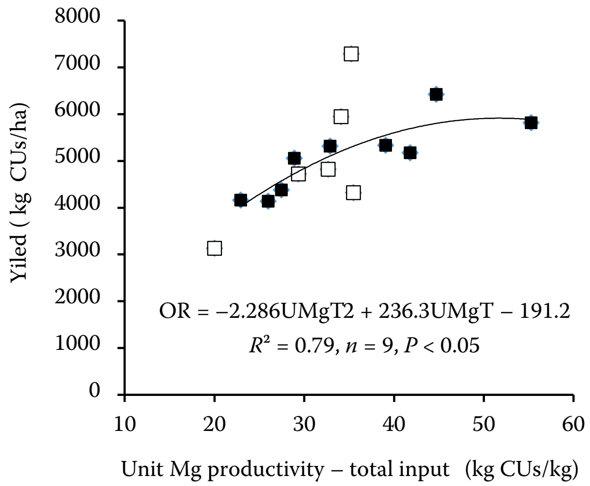

Figure 1. Trends of yield in two different cropping sequences based on the total magnesium input

The analysis of Mg budget, based on complementarities of these two methods (Oenema et al. 2003), implicitly corroborated the hypothesis on the quite different impact of oilseed rape and maize on Mg management (Figures 2 and 4). The average value of the net magnesium balance (NMgB), was –1.8 kg

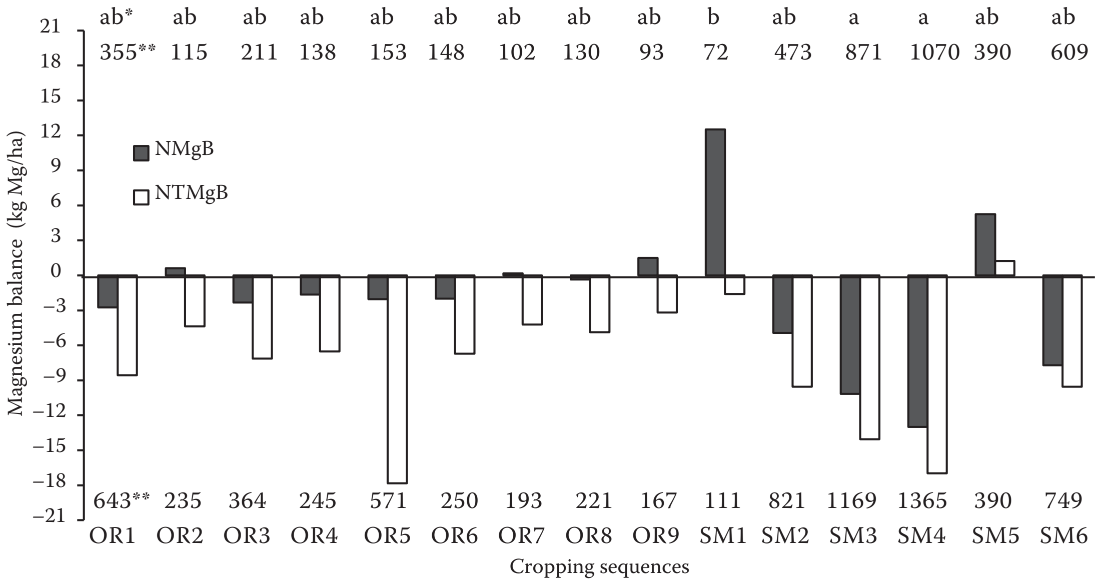

Figure 2. The effect of cropping sequence on the net and total magnesium (Mg) balance and efficiency. *net Mg balance; **net Mg efficiency (%); ***total Mg efficiency (%). NMgB – net magnesium balance; NTMgB – total magnesium balance; OR – winter oil-seed rape; SM – silage/grain maize

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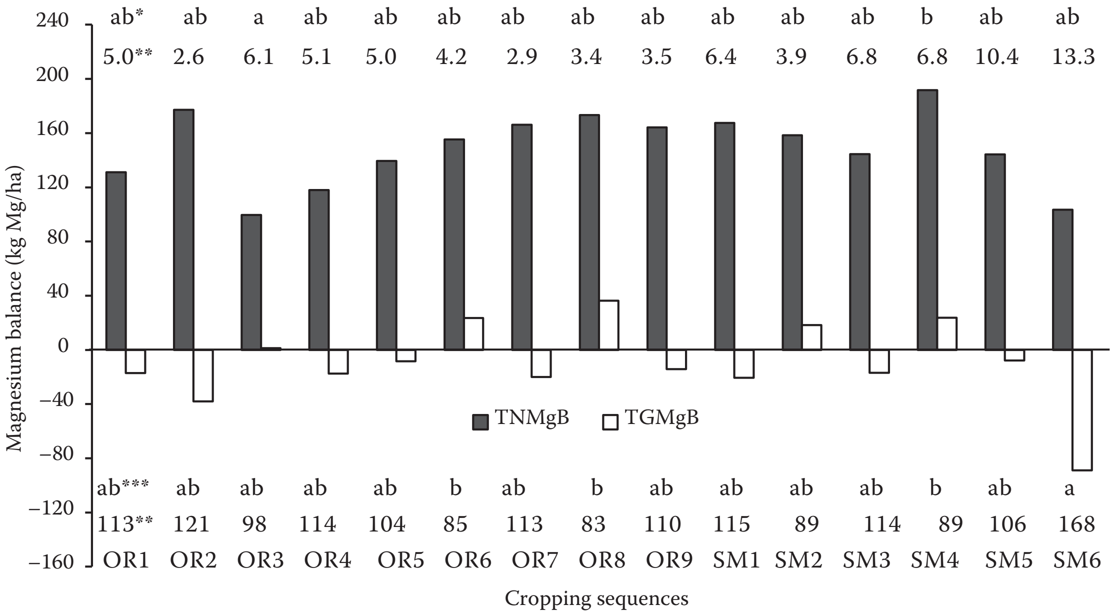

Figure 4. The effect of cropping sequence on the net and total magnesium (Mg) balance and efficiency. *total net Mg balance; **total net Mg efficiency (TNMgB, %); ***total gross Mg balance (TGMgB); ****total gross Mg efficiency (%)

Mg/ha. A more negative NMgB was recorded in the OR-CS. In the SM-CS, this trend, except the SM6, was deeper in fields with maize grown without manure. As a result of low Mg input, the net Mg efficiency was enormous, varied from 72% (SM1) to 1070% (SM4). This index clearly confirms the importance of soil Mg supply to the growing crops, especially to maize. The negative balance of Mg can increase, when crop residues are exported from the field. It refers mainly to OR-CSs, which residues are rich in cations (Holmes 1980).

The pattern of Mg_I impact on NMgB indices was linear as a rule, but at the same time crop specific (Figure 3). The quantity of the externally added Mg to balance its net output was 5.8 kg/ha in the OR-CS, but twice as high in the SM-CS (10.4 kg/ha) one. Consequently, the Mg rate of 5.0 kg as applied to the OR5 was sufficient to reach the balance. The double value of the NMgB in maize fields implicitly suggests a much higher need of this crop for magnesium. The required amount of Mg, as recorded in the SM4 field (the highest yield), was taken up by plants from soil resources. The yield can be predicted based on the net total Mg balance. The yield increased in accordance with the NTMgB gap. It was significant for all the cropping sequences, but especially for the OR-CS one:

$$Y = -126.3 + 4106 \quad \text{for } n = 15;\ R^2 = 0.44 \text{ and } P \leq 0.01 \tag{7}$$

$$\text{Y-OR} = -147.5\ \text{NMgB} + 4047 \quad \text{for } n = 9,\ R^2 = 0.71 \text{ and } P \leq 0.001 \tag{8}$$

The above presented equations clearly indicate importance of soil Mg pool as a key resource for the growing crops (Grzebisz et al. 2010). This conclusion is fully corroborated by soil system balance (SSyB) indices. The average TGMgB decreased by 10 kg/ha (Figure 4). The Mg gap was covered from soil resources, as results from indices of the total

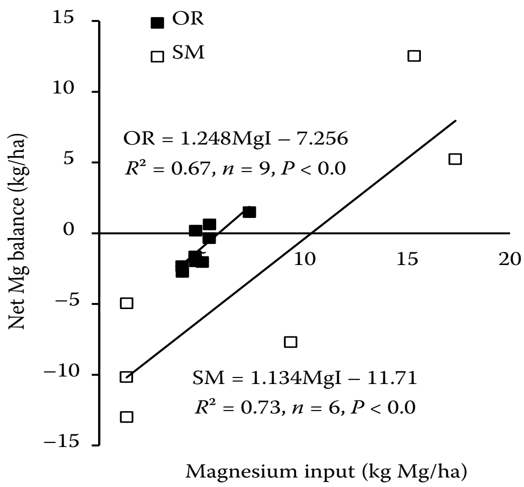

Figure 3. The net magnesium (Mg) balance as a function of Mg input (MgI) in dependence on the type of cropping sequence. OR – winter oil-seed rape; SM – silage/grain maize

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Table 3. Temporal and vertical distribution of soil available magnesium content in dependence on cropping sequence

Field	Main factors								Significance of interactions			
	years (Y)			sampling date (D)		layers (L)			Y × D	Y × L	D × L	Y × D × L
	2005	2006	2007	S	A	A	B	C				
OR1	157^{b}	126^{a}	132^{ab}	138	142	161^{b}	130^{a}	124^{a}	*	ns	ns	*
OR2	194	190	194	177^{a}	211^{b}	192	203	186	ns	ns	**	ns
OR3	100^{b}	80^{a}	113^{c}	80	93	105	89	97	*	ns	ns	ns
OR4	135	118	140	120	131	146^{b}	132^{ab}	120^{a}	ns	ns	*	ns
OR5	126^{a}	115^{a}	170^{b}	140	132	136	128	146	ns	ns	ns	ns
OR6	169^{b}	119^{a}	139^{ab}	158^{b}	127^{a}	132^{a}	130^{a}	165^{b}	*	**	ns	ns
OR7	242^{b}	131^{a}	149^{a}	166	182	181	157	184	ns	**	***	ns
OR8	178^{b}	109^{a}	172^{b}	174^{b}	132^{a}	158	154	147	***	ns	ns	**
OR9	169^{b}	142^{a}	194^{c}	163^{a}	174^{b}	163	165	140	*	ns	ns	ns
SM1	153^{a}	176^{b}	196^{c}	165^{a}	184^{b}	182^{b}	182^{b}	159^{a}	***	ns	***	***
SM2	132^{a}	132^{a}	185^{b}	163^{b}	135^{a}	142	153	155	ns	ns	ns	ns
SM3	182^{c}	124^{a}	162^{b}	155	158	173	149	146	ns	ns	ns	ns
SM4	208^{b}	161^{a}	184^{ab}	205^{b}	163^{a}	185	190	177	***	ns	ns	ns
SM5	165^{b}	105^{a}	204^{b}	143	151	161	145	138	ns	ns	ns	ns
SM6	97^{a}	153^{b}	204^{c}	111^{a}	190^{b}	159	150	143	**	ns	ns	ns

[a]numbers marked with the same letter are not significantly different; ***$P \leq 0.001$; **$P \leq 0.01$; *$P \leq 0.05$; ns – non significant; OR – winter oil-seed rape; SM – silage/grain maize

gross Mg efficiency (TGMgE), in 10 of 15 fields. The temporary status of TGMgB was importantly affected by the type of cropping system and content of soil available Mg in spring. For the SM-CS any increase in Mg_{sav} in spring resulted in the index increase. This dependence was not important for the OR-CS. This discrepancy can be partly explained by analysis of the relationship between the TNMgB and $UMgP_{TI}$. It was significant only for the OR-CS:

$$UMgP_{TI} = -0.373\ TNMgB + 90.38 \quad \text{for } n = 9;\ R^2 = 0.90 \text{ and } P \leq 0.001 \qquad (9)$$

This equation clearly informs that any increase in TNMgB gap resulted in higher productivity of Mg taken up by crops in the OR-CSs. In the case

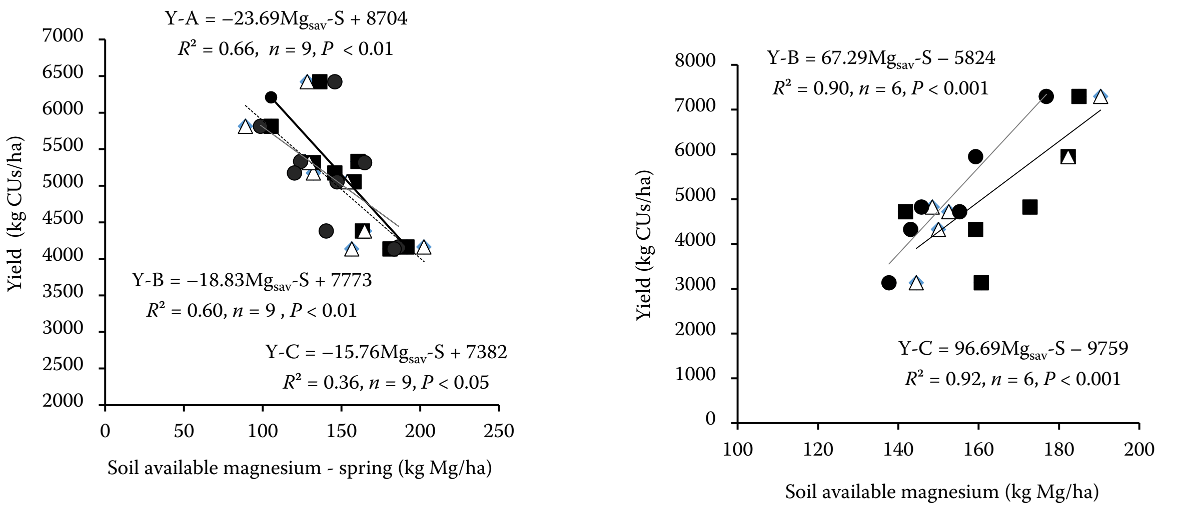

Figure 5. Yield prediction based on available magnesium (Mg) content in respective soil layers: (a) OR – oilseed rape cropping sequences; (b) MS – maize cropping sequences. Soil layers: 0–30 (A), 31–60 (B); 61–90 cm (C)

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of SM-CS, the $UMgP_{TI}$ did not show a response to the Mg balance.

In the study, a significant impact of weather on year-to-year variability in soil available Mg content (Mg_{sav}) was observed in 15 of 17 fields (Table 3). The important decrease of Mg_{sav} in autumn compared to spring was the attribute of four fields, including the SM4 with the top yield. Net increases were observed in five fields, being the strongest in the SM6. The content of Mg_{sav} decreased with depth in 5 of 15 fields. A specific impact of cropping sequence on Mg_{sav} content in spring was observed on yield. In the OR fields, the yield did not show dependence on its resources in the whole studied soil profile (Figure 5a). The coefficient of direction for each developed equation was negative, in turn indicating an oversupply of $Mg_{sav\text{-}S}$. A quite different trend was observed in fields with maize (Figure 5b). Coefficients of direction and R^2 showed a constant increase with depth, indirectly stressing an importance of soil Mg for crops grown in the SM-CS. This study corroborates sensitivity of maize to magnesium supply (Potarzycki 2011).

The different response of both cropping sequences to the source of Mg clearly stresses the impact of the dominant crop on Mg management. A sufficient supply of Mg to maize depends on mechanisms responsible for its uptake. Oilseed rape plants show much higher utilization efficiency of Mg taken up from external or soil resources.

REFERENCES

Brankatschk G., Finkbeiner M. (2014): Application of the Cereal Unit in a new allocation procedure for agricultural life cycle assessments. Journal of Cleaner Production, 73: 72–79.

Grzebisz W., Przygocka-Cyna K., Szczepaniak W., Diatta J., Potarzycki J. (2010): Magnesium as a nutritional tool of nitrogen management – Plant production and environment. Journal of Elementology, 15: 771–788.

Holmes M.R.J. (1980): Nutrition of the Oilseed Rape Crop. London, Applied Science Publishers LTD, 158.

Houba V.J.G., Temminghoff E.J.M., Gaikhorst G.A., van Vark W. (2000): Soil analysis procedures using 0.01 M calcium chloride as extraction reagent. Communications in Soil Science and Plant Analysis, 31: 1299–1396.

Oenema O., Kros H., de Vries W. (2003): Approaches and uncertainties in nutrient budgets: Implications for nutrient management and environmental policies. European Journal of Agronomy, 20: 3–16.

Piechota T., Blecharczyk A., Małecka I. (2000): Effect of long-term organic and mineral fertilization on nutrients content in soil profile. Folia Universitatis Agriculturae Stetinensis. Agricultura, 84: 393–398.

Potarzycki J. (2011): Effect of magnesium and zinc supplementation at the background of nitrogen rate on nitrogen management by maize canopy cultivated in monoculture. Plant, Soil and Environment, 57: 19–25.

Shaul O. (2002): Magnesium transport and function in plants: The tip of the iceberg. Biometals, 15: 309–323.

Szczepaniak W., Grzebisz W., Potarzycki J., Łukowiak R., Przygocka-Cyna K. (2015): Nutritional status of winter oilseed rape in cardinal stages of growth as the yield indicator. Plant, Soil and Environment, 61: 291–296.

Zatloukalová A., Lošák T., Hlušek J., Pavloušek P., Sedláček M., Filipčík R. (2011): The effect of soil and foliar applications of magnesium fertilisers on yields and quality of vine (*Vitis vinifera*, L.) grapes. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, LIX: 221–226.

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