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ORIGINAL PAPER

CONTENT OF MAGNESIUM AND CALCIUM IN CULTIVATED PLANTS DEPENDING ON VARIOUS SOIL SUPPLY WITH NITROGEN, POTASSIUM, MAGNESIUM AND SULFUR

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Abstract

In view of the important role of magnesium and calcium in yield formation, this study has been undertaken to analyze the Mg and Ca content in winter forms of oilseed rape and wheat as well as in spring barley in the context of a certain deficiency of some nutrients (N, K, Mg, S) in the plant growth environment. The present study also evaluated the effect of meteorological conditions on the magnesium and calcium content in the test plants. The research hypothesis is that mineral fertilization and meteorological conditions significantly affect the content of magnesium and calcium in the test plants. A four-year, two-factor experiment was established on soil with the particle-size distribution of silt loam. It was shown that the investigated experimental factors (mineral fertilization and years of experiment) resulted in distinctly seen differences in the magnesium and calcium content in the test plants. In winter oilseed rape, this study found a significant decrease in the content of magnesium in seeds when there was a deficity of this nutrient in fertilization, and a decrease in the calcium content in the generative organs if nitrogen, potassium and magnesium were excluded from a fertilizer dose. A significant reduction in the calcium content in winter wheat straw was associated with nitrogen deficiency in fertilization, whereas the lack of potassium in fertilization resulted in a significant increase in the calcium content in winter wheat straw. In the case of spring barley, nitrogen deficiency in the plant growth environment resulted in a significant decrease in the calcium content in the vegetative organs, deficiency of magnesium contributed to a significant decrease in its concentration in grain and straw, while the lack of sulfur caused a significant reduction in the Mg content and a significant increase in the Ca content in straw. The meteorological conditions during the experiment had a significant effect on the magnesium and calcium content in the test plants.

Keywords: mineral fertilization, magnesium, calcium, winter rape, winter wheat, spring barley.

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INTRODUCTION

Magnesium and calcium belong to elements whose deficiency is a factor limiting both the quantity and quality of yields (Brodowska, Kaczor 2009). The role of magnesium in plant organisms arises from its ability to interact with nucleophilic ligands (Shaul 2002). Magnesium is the central atom of a chlorophyll molecule and forms bridge bonds in the aggregation of ribosome subunits necessary for protein synthesis (Senbayram 2015). This element is essential for the functioning of many enzymes which include RNA polymerases, ATPases, protein kinases, phosphatases, glutathione cytases, and carboxylases (Williams et al. 2000). In turn, the role of calcium in plant fertilization most frequently consists of improving soil physicochemical properties, whereas its contribution to yield formation is ignored in most cases. Nevertheless, calcium performs a number of important functions in the metabolism of plants, which affect their growth and development (Gilliham et al. 2011). Calcium participates in mitotic cell divisions occurring in the meristem, which are particularly important in the process of root system development and root hair formation, and its deficit in the soil causes quick death of the apical meristem and consequently inhibits the plant growth (Bush 1995). Calcium also contributes to prolonged photosynthetic activity and extends the time of production of assimilates, owing to which the plant produces a higher yield. Moreover, calcium plays a role in maintaining the water balance in plants and together with potassium it is responsible for the closing and opening of stomata (Hepler 2005), whereas under drought conditions it stabilizes protein structures, which increases plant resistance to water deficit (Medevdev 2005).

A wide array of physiological roles of magnesium and calcium implicates many dangers for the normal growth and development of plants whenever these elements are deficient. Another consequence is an insufficient supply in other trophic chain links. Apart from the meteorological conditions, one of the most important factors which determines the content of nutrients in plants is mineral fertilization. Therefore, the aim of our study was to assess the impact of nitrogen, potassium, magnesium and sulfur shortage on the magnesium and calcium content in the test plants. The research hypothesis is that mineral fertilization and meteorological conditions significantly affect the magnesium and calcium content in winter forms of oilseed rape and wheat and in spring barley.

MATERIAL AND METHODS

A field experiment was established at the Experimental Station of the University of Natural Sciences in Lublin. The experiment was conducted from 2005 to 2009, and it was set up in a split-plot design with four replicates, on lessive brown soil with the particle-size distribution of silt loam, classified in agronomy as heavy soil (41% of the fraction<0.02 mm) and soil quality class II, and as good wheat soil complex in terms of agricultural land suitability. Before the experiment, the soil had slightly acidic pH, very high phosphorus availability (159.5 mg P kg^{-1}), high potassium availability (218 mg K kg^{-1}), medium magnesium availability (72 mg Mg kg^{-1}) and low sulfur availability (11.9 mg S kg^{-1}).

The plant species included in the experiment were winter oilseed rape (*Brassica napus* L.) cv. Kana, winter wheat (*Triticum aestivum* L.) cv. Sukces, and spring barley (*Hordeum vulgare* L.) cv. Justina. The experimental factors were fertilization regimes (5 levels) and years (4 levels). Mineral fertilization applied in this study was adjusted to the nutritional requirements of the plant species tested (Table 1).

Table 1

Doses of nutrients components

Object	Fertilization	Doses (kg ha^{-1}) N:P:K:Mg:S		
		winter rape	winter wheat	spring barley
1	control (NPKMgS)	140:31:133:18:60	150:17:66:18:24	100:17:66:18:24
2	without N (PKMgS)	0:31:133:18:60	0:17:66:18:24	0: 17:66:18:24
3	without K (NPMgS)	140:31:0:18:60	150:17:0:18:24	100:17:0:18:24
4	without Mg (NPKS)	140:31:133:0:60	150:17:66:0:24	100:17:66:0:24
5	without S (NPKMg)	140:31:133:18:0	150:17:66:18:0	100:17:66:18:0

In this field experiment, nitrogen was applied as ammonium nitrate (NH_4NO_3 – 33.5% N), whereas phosphorus was used as triple superphosphate (40% P_2O_5) in the treatment without sulfur fertilization and as single superphosphate (19% P_2O_5 + 12% S) in the other treatments. Potassium was applied as potassium salt 60% (60% K_2O) in the treatments without sulfur and as potassium sulfate (K_2SO_4 – 50% K_2O + 18% S) in the treatments with sulfur addition. Similarly, magnesium was applied as magnesium chloride ($MgCl_2$ – 20% MgO) and magnesium sulfate ($MgSO_4\,H_2O$ – 25% MgO + 20% S). Sulfur was applied as single superphosphate (19% P_2O_5 + 12% S), magnesium sulfate ($MgSO_4H_2O$ – 25% MgO + 20% S) and potassium sulfate (K_2SO_4 – 50% K_2O + 18% S). Fertilization followed appropriate agronomic practice recommendations.

The magnesium and calcium content was determined by ASA after mineralization of the plant material in concentrated sulfuric(VI) acid with 30% addition of H_2O_2.

Table 2

Sielyaninov's coefficient values during the field research period

Years	Months						
	April	May	June	July	August	September	October
2005	1.50	2.14	1.33	0.50	0.91	0.40	0.87
2006	1.84	1.20	0.62	0.39	2.46	0.02	0.31
2007	0.73	0.76	1.03	1.38	0.55	3.34	1.13
2008	2.23	1.61	0.84	2.22	1.56	2.44	1.41
2009	0.46	1.62	1.78	0.33	0.46	0.96	3.42

For a more complete description of the meteorological conditions, the Selyaninov's hydrothermal coefficient was calculated (Table 2); this coefficient shows the water supply to plants during the growing season (SKOWERA, PUŁA 2004). The following value ranges of the Sielyaninov's hydrothermal coefficient are generally accepted: $k \leq 0.4$ – extremely dry conditions; $0.4 < k \leq 0.7$ – very dry conditions; $0.7 < k \leq 1.0$ – dry conditions; $1.0 < k \leq 1.3$ – quite dry conditions; $1.3 < k \leq 1.6$ – optimum conditions, $1.6 < k \leq 2.0$ – quite moist conditions; $2.0 < k \leq 2.5$ – moist conditions; $2.5 < k \leq 3.0$ – very moist conditions; $k > 3.0$ extremely moist conditions.

The results obtained from this experiment were statistically analyzed by ANOVA (for the factorial designs) using Statistica 9.0 PL software. Statistically homogeneous groups and LSD values were determined by the Tukey's HSD test at a level of significance 〈 = 0.05.

RESULTS AND DISCUSSION

Depending on the mineral fertilization applied, the magnesium and calcium content in the generative and vegetative organs of the test plants varied distinctly (Tables 3,4,5). The determined concentrations of these elements in all the test plants were similar to those most frequently found in these plants (MATYKA et al. 1993, KOROL et al. 1994, STĘPIEŃ et al. 2009). An exception was the third year of the experiment, when the calcium concentration was definitely higher in all the plants studied.

In the present experiment, similarly as in the studies by BRZOZOWSKA (2008) and WOJTKOWIAK (2014), nitrogen deficiency in the plant growth environment did not cause statistically significant differences in the magnesium content in the generative and vegetative organs of the test plants in most of the treatments analyzed. However, CHERNEY et al. (2004) as well as BRODOWSKA, KACZOR (2009) demonstrated that fertilization with nitrogen applied as ammonium nitrate(V) results in an increase in the magnesium

Table 3

Content of magnesium and calcium in seeds and straw of winter rape

Specification	Mineral fertilization (A)	Year of experiment (B)									
		I	II	III	IV	mean	I	II	III	IV	mean
		magnesium					calcium				
Seeds	NPKMgS	3.141	3.058	7.415	3.588	4.301	4.430	4.130	11.28	3.493	5.833
	PKMgS	3.114	3.366	5.558	3.576	3.904	4.325	3.995	9.600	2.943	5.216
	NPMgS	3.130	3.071	6.035	3.601	3.959	4.385	4.405	9.930	3.195	5.479
	NPKS	3.048	2.991	6.438	3.661	4.035	4.438	4.105	10.69	3.450	5.671
	NPKMg	3.138	3.008	7.618	3.503	4.317	4.209	4.295	11.65	3.283	5.859
	Mean	3.114	3.099	6.613	3.586	4.103	4.357	4.186	10.63	3.273	5.612
$LSD_{0.05}$		A – 0.185 B – 0.185 AxB – 0.486					A – 0.371 B – 0.312 AxB – 11.28				
Straw	NPKMgS	0.823	0.750	1.865	0.683	1.030	8.288	9.065	26.41	8.638	13.10
	PKMgS	0.829	0.723	1.779	0.790	1.030	8.313	8.835	30.46	8.388	13.99
	NPMgS	0.750	0.763	1.900	0.721	1.034	8.494	11.10	29.23	10.15	14.74
	NPKS	0.741	0.637	1.879	0.608	0.967	8.176	9.155	38.60	8.775	16.18
	NPKMg	0.898	0.663	1.940	0.743	1.061	8.775	8.745	26.81	8.625	13.24
	Mean	0.808	0.707	1.873	0.709	1.024	8.409	9.380	30.30	8.915	14.25
$LSD_{0.05}$		A – n.s. B – 0.110 AxB – n.s.					A – 2.201 B – 1.850 AxB – 5.796				

factor A – mineral fertilization, factor B – year of experiment, p-value = 0.05

content in the treatments studied. As regards the calcium content, the omission of ammonium nitrogen in a fertilizer dose caused a reduction in its concentration in most of the treatments analyzed relative to the control. A statistically significant decrease in the Ca content was found in winter oilseed rape seeds as well as in winter wheat and spring barley straw (Table 2). These results are in agreement with the study by Zebarth et al.(1992), who found an approximately 20% increase in the calcium content in winter wheat grain as a result of the incorporation of nitrogen into the plant growth environment. On the other hand, Buczek et al. (2008) found a similar calcium content in winter wheat in both nitrogen-fertilized and unfertilized treatments.

The present study did not reveal an unambiguous effect of potassium deficiency in the plant growth environment on the magnesium and calcium content in the test plants. The lack of potassium in fertilization was associated with a significant reduction in the calcium content in winter oilseed rape seeds and a significant increase in the magnesium and calcium content in its

Table 4

Content of magnesium and calcium in grain and straw of winter wheat

Specification	Mineral fertilization (A)	Year of experiment (B)									
		I	II	III	IV	mean	I	II	III	IV	mean
		magnesium					calcium				
Grain	NPKMgS	1.160	1.095	1.903	1.271	1.357	0.134	0.225	1.250	0.160	0.442
	PKMgS	1.218	1.062	2.064	1.183	1.382	0.138	0.255	1.216	0.129	0.435
	NPMgS	1.148	1.114	1.963	1.220	1.361	0.131	0.330	1.200	0.168	0.457
	NPKS	1.145	1.094	1.655	1.213	1.277	0.120	0.235	1.288	0.166	0.452
	NPKMg	1.185	1.104	1.894	1.265	1.362	0.215	0.220	1.188	0.168	0.448
	Mean	1.171	1.094	1.896	1.230	1.348	0.148	0.253	1.228	0.158	0.447
$LSD_{0.05}$		A – n.s. B – 0.107 AxB – n.s.					A – n.s. B – 0.075 AxB – n.s.				
Straw	NPKMgS	0.572	0.716	1.495	0.848	0.908	1.490	3.200	4.810	2.193	2.923
	PKMgS	0.709	0.576	1.398	0.890	0.893	1.065	2.195	4.075	1.515	2.213
	NPMgS	0.611	0.788	1.414	0.926	0.935	1.460	3.660	5.125	2.353	3.150
	NPKS	0.540	0.767	1.325	0.823	0.864	1.380	3.460	5.188	2.490	3.130
	NPKMg	0.555	0.787	1.356	0.839	0.884	1.410	3.520	4.250	2.243	2.856
	Mean	0.597	0.727	1.398	0.865	0.897	1.361	3.207	4.690	2.159	2.854
$LSD_{0.05}$		A – n.s. B – 0.046 AxB – 0.144					A – 0.342 B – 0.287 AxB – 0.900				

factor A – mineral fertilization, factor B – year of experiment, *p*-value = 0.05.

straw. The study by GAJ (2010) proves that under the influence of potassium fertilization, the leaf magnesium and calcium content is significantly increased in oilseed rape at the initial elongation growth stage. In this experiment, potassium deficiency had caused a significant increase in the calcium content in winter wheat and spring barley straw, which is in agreement with the results of STĘPIEŃ et al.(2009), who found a small decrease in the calcium content in the test plants as effected by potassium fertilization. Another study (STĘPIEŃ et al. 2005) did not find potassium fertilization to affect the calcium content in spring barley straw. In this study, the lack of potassium in a fertilizer dose did not significantly influence the amount of calcium in grain of the test plants. WIERZBOWSKA (2006) found a slight increase in the calcium content in winter wheat grain due to potassium fertilization.

In the present experiment, deficiency of magnesium in the plant growth environment had the strongest effect on its content in the test plants, which is consistent with the results obtained by WYSZKOWSKI (2001), who found that

Table 5

Content of magnesium and calcium in grain and straw of spring barley

Specification	Mineral fertilization (A)	Year of experiment (B)									
		I	II	III	IV	mean	I	II	III	IV	mean
		magnesium					calcium				
Grain	NPKMgS	0.974	0.981	1.236	0.989	1.045	0.157	0.255	0.850	0.213	0.369
	PKMgS	0.906	0.953	1.380	0.949	1.047	0.127	0.205	1.000	0.194	0.382
	NPMgS	0.979	0.955	1.433	1.004	1.093	0.157	0.220	0.988	0.203	0.392
	NPKS	0.918	0.943	1.303	0.956	1.030	0.159	0.220	0.963	0.210	0.388
	NPKMg	0.943	0.971	1.438	1.013	1.092	0.158	0.195	0.913	0.214	0.370
	Mean	0.944	0.961	1.358	0.982	1.061	0.152	0.219	0.943	0.207	0.380
$LSD_{0.05}$		A – n.s. B – 0.078 AxB – n.s.					A – n.s. B – 0.047 AxB – n.s.				
Straw	NPKMgS	0.294	0.417	0.630	0.464	0.451	2.563	4.225	4.725	2.525	3.510
	PKMgS	0.241	0.532	0.583	0.488	0.461	2.913	3.885	4.438	2.243	3.370
	NPMgS	0.279	0.388	0.588	0.511	0.442	3.275	3.480	5.575	2.948	3.820
	NPKS	0.243	0.382	0.503	0.454	0.396	2.975	4.065	5.125	2.513	3.670
	NPKMg	0.275	0.402	0.623	0.499	0.450	3.450	3.790	4.825	2.685	3.688
	Mean	0.266	0.424	0.585	0.483	0.440	3.035	3.889	4.938	2.583	3.611
$LSD_{0.05}$		A – 0.020 B – 0.017 AxB – 0.052					A – 0.292 B – 0.245 AxB – 0.768				

factor A – mineral fertilization, factor B – year of experiment, *p*-value = 0.05.

fertilization with magnesium, compared to other macronutrients, causes the greatest and significant changes in the content of this nutrient in plants. The current study results reveal a clear decrease in the magnesium content in all the plants analyzed due to the lack of fertilization with this nutrient, which also resulted in a significant increase in the calcium content in winter oilseed rape straw and its decrease in seeds. In the case of winter wheat, an increase in the calcium concentration was found both in the generative and vegetative organs, whereas in spring barley no clear relationships were revealed between the absence of magnesium in plant fertilization and the amount of calcium in the plants. The study by Głębowski et al. (2001) found magnesium fertilization to have an effect on decreasing the calcium content in oat.

Sulfur deficiency in the plant growth environment resulting from the lack of sulfur in fertilization as well as low sulfur availability in soil before the experiment led to an increase in the Mg content in winter oilseed rape straw and its decrease in winter wheat and spring barley straw. However, this experiment did not reveal an unambiguous effect of sulfur deficiency on the magnesium content in winter wheat and spring barley straw. Podleśna (2004, 2009, 2010) and Lošák (2000) demonstrated that sulfur fertilization increases the calcium content in the vegetative and generative organs of winter oilseed rape, while Brodowska, Kaczor (2009) showed sulfur fertilization to have an effect on increasing the calcium content in both straw and grain of spring wheat. The present study found that the calcium content increased in both straw and grain of spring barley as a result of the omission of sulfur in fertilization. The literature provides evidence that the inclusion of sulfur in fertilization contributes to an increase in the calcium content in spring wheat grain (Skwierawska et al. 2006). In spring barley straw, however, the same authors reported that the calcium content decreased in sulfur-fertilized treatments.

The weather conditions during this field experiment clearly varied in terms of both average monthly temperatures and rainfall intensity and distribution in particular years of the study. The third year of the experiment was characterized by the highest average annual temperature (10.4°C) and it was also a year with the highest annual total rainfall (743.4 mm), whereas 2005 was the coldest year (8.8°C) and 2006 was the driest one (492.5 mm).

The content of the macronutrients studied in all the tested treatments significantly varied depending on meteorological conditions. Rutkowska (2004), Gaj, Górski (2014) and Jankowski et al. (2014) revealed a similar relationship in their research. In all the treatments analyzed, statistically significant differences in the magnesium and calcium content were found depending on the year of the experiment. In most of the plants analyzed, the lowest content of both micronutrients investigated occurred in 2006, which could have been attributed to the periodically extremely dry conditions in that year. In the first year of the experiment, September and October were characterized by extremely low rainfalls (Spetember – 15.8 mm, the multi-year average being 59.1 mm, October – 24.9 mm, the multi-year average being 39.4 mm), which ensures very poor conditions for the sprouting of winter rape and sowing and sprouting of winter wheat. Likewise, during the spring barley development, the monthly total of rainfalls in June amounted to 42.6 mm, while the multi-year average is 61.7 mm. Soil water deficit initiates the processes of solidification and then crystallization of bonds between phosphorus, aluminum and calcium, which leads to a decrease in the content of minerals available to plants (Gaj, Górski 2014). On the other hand, the highest calcium and magnesium content in all the test plants appeared in 2008, which could have been caused by the optimal hydrothermal conditions. During the sprouting of winter oilseed rape and the sowing and sprouting of winter wheat in the third year of the experiment, there were high monthly total of rainfalls (144.2 mm, while the multi-year average was 59.1 mm). A similar relationship was observed for spring barley (the total monthly of rainfalls in July was 139.3 mm, compared to the multi-year average of 87.1 mm).

In the present study, the interaction of both experimental factors resulted in significant differences in the magnesium and calcium content in winter oilseed rape seeds and winter wheat and spring barley straw.

CONCLUSIONS

1. The lack of nitrogen, potassium, magnesium and sulfur in fertilization resulted in modification of the magnesium and calcium content in the test plants. The most distinct response was observed in winter oilseed rape.

2. The omission of nitrogen in a fertilizer dose resulted in a decrease in the calcium content in winter oilseed rape seeds, winter wheat straw as well as in spring barley grain and straw.

3. The lack of potassium in a fertilizer dose increased the calcium content in the vegetative organs of all the test plants.

4. Deficiency of magnesium in the plant growth environment resulted in a decrease in its content in all the plants, an increase in the calcium content in winter wheat grain and straw as well as in winter oilseed rape straw, and also in a decrease in its content in oilseed rape seeds.

5. Sulfur deficiency in the plant growth environment is associated with an increase in the content of magnesium in winter oilseed rape straw and its decrease in winter wheat and spring barley straw. The omission of sulfur in a fertilizer dose significantly increases the calcium content in the vegetative and generative organs of spring barley.

6. Among the experimental factors analyzed, the magnesium and calcium content in the vegetative and generative organs of the test plants was primarily determined by the meteorological conditions during the field experiment.

REFERENCES

Brodowska M.S., Kaczor A. 2009. *The effect of various forms of sulphur and nitrogen on calcium and magnesium content and uptake in spring wheat (Triticum aestivum* L.*) and cocksfoot (Dactylis glomerata* L.*).* J. Elem., 14(4): 641-647. DOI: 10.5601/jelem.2009.14.4.641-647

Brzozowska I. 2008. *Macroelement content in winter wheat grain as affected by cultivation and nitrogen application methods.* Acta Agrophys., 11(1): 23-32.

Buczek J., Kryńska B., Tobiasz-Salach R. 2008. *Response of winter wheat to soil fertilization and foliar nitrogen application.* Ann. UMCS, Sect. E, 63(4) E, 48-57. (in Polish)

Bush D.S. 1995. *Calcium regulation in plant cells and its role in signalling*. Annu. Rev. Plant Physiol. Plant Mol. Biol., 46: 95-122. DOI: 10.1146/annurev.pp.46.060195.000523

Cherney J.H., Ketterings Q.M., Orloski J.L. 2004. *Plant and soil elemental status as influenced by multi-year nitrogen and potassium fertilization.* J. Plant Nutrit., 27(6): 991-1014. DOI: http://dx.doi.org/10.1081/PLN-120037532

Gaj R.2010. *Effect of different level of potassium fertilization on winter oilseed rape nutritional status at the initiation of the main stem growth and on the seed field.* Rośl. Oleiste, 31: 115-124. (in Polish)

GAJ R., GÓRSKI D. 2014. *Effects of different phosphorus and potassium fertilization on contents and uptake of macronutrients (N, P, K, Ca, Mg) in winter wheat.* I. *Content of macronutrients.* JCEA, 15(4): 169-187. DOI: 10.5513/JCEA01/15.4.1526

GILLIHAM M., DAYOD M., HOCKING B.J., XU B., CONN S.J., KAISER B.N., LEIGH R.A., TYERMAN S.D. 2011. *Calcium delivery and storage in plant leaves: exploring the link with water flow.* J. Exp. Bot., 62(7): 2233-50. DOI: 10.1093/jxb/err111.

GŁĘBOWSKI H., RUTKOWSKA B., SZULC W. 2001. *Influence of magnesium fertilization and liming on yielding and chemical composition of oat.* Zesz. Probl. Post. Nauk Rol., 480: 223-231. (in Polish)

HEPLER P.K. 2005. *Calcium: A central regulator of plant growth and development.* Plant Cell, 17: 2142-2155. DOI: 10.1105/tpc.105.032508

JANKOWSKI K.J., BUDZYŃSKI W.S., KIJEWSKI Ł., KLASA A. 2014. *Concentrations of copper, zinc and manganese in the roots, straw and oil cake of white mustard (Sinapis alba* L.*) and Indian mustard (Brassica juncea* L. Czern. *et* Coss.*) depending on sulfur fertilization.* Plant Soil Environ., 60(8): 364-371.

KOROL W., JAŚKIEWICZ T., BARTUZI G., BOGUSZ G., NIEŚCIOR H., GRABOWSKI C., MOJEK E. 1994. *Chemical composition of rape seed from low glucosinolate varietes grown in Poland.* J. Anim. Feed Sci., 3: 57-64.

LOŠÁK T., HŘIVNA L., RICHTER R. 2000. *Effect of increasing doses of nitrogen and sulphur on yields, quality and chemical composition of winter rape.* Zesz. Probl. Post. Nauk Rol., 472: 481-487.

MATYKA S., KOROL W., WÓJCIAK M. 1993. *The mineral composition of cereals grain.* Zesz. Nauk. WSRP, Zootechnika, 32: 51-55. (in Polish)

MEDEVDEV S.S. 2005. *Calcium singnaling system in plants.* Russ. J. Plant Physl., 52: 249-270.

PODLEŚNA A. 2004. *The effect of sulfur fertilization on concentration and uptake of nutrients by winter oilseed rape.* Rośl. Oleiste, 35: 627-636. (in Polish)

PODLEŚNA A. 2009. *The effect of soil and foliar application of sulfur on the yield and mineral composition of winter oilseed rape plants.* Ann. UMCS, Sect. E, 64(1): 68-75. (in Polish)

PODLEŚNA A. 2010. *Effect of sulfur and nitrogen on yielding and elemental composition of the spring oilseed rape.* Zesz. Probl. Post. Nauk Rol., 556: 211-217. (in Polish)

RUTKOWSKA A., 2004. *Studies on winter wheat fertilization with nitrogen.* Fertilizers and Fertilization, 4, 30-45. (in Polish)

SENBAYRAM M., GRANSEE A., WAHLE V., THIEL H. 2015. *Role of magnesium fertilizers in agriculture: plant – soil continuum.* Crop Pasture Sci., 66: 1219-1229. DOI: http://dx.doi.org/10.1071/CP15104

SHAUL O. 2002. *Magnesium transport and function in plants: the tip of the iceberg.* Biometals, 15(3): 307-321.

SKOWERA B., PUŁA J. 2004. *Pluviometric extreme conditions in spring season in Poland in the years 1971-2000.* Acta Agrophys., 3(1): 171-177. (in Polish)

SKWIERAWSKA M., ZAWADZKI B., ZAWARTKA L., NOGALSKA A. 2006. *Influence of different doses and forms of sulphur on calcium content and its uptake by plants.* Zesz. Probl. Post. Nauk Rol., 512: 545-554. (in Polish)

STĘPIEŃ W., MERCIK S., SOSULSKI T. 2005. *The influence of potassium form and methods of application on the yield and quality of selected crops.* Fertilizers and Fertilization, 3(24): 401-408. (in Polish)

STĘPIEŃ W., RUTKOWSKA B., SZULC W. 2009. *Effect of different potassium fertilizers on yield and quality of plants.* Zesz. Probl. Post. Nauk Rol., 538: 251-256. (in Polish)

WIERZBOWSKA J. 2006. *Calcium and magnesium management in plant of spring wheat in conditions of growth regulators and increasing potassium doses use.* J. Elementol., 11(1): 109-118. (in Polish)

WILLIAMS L.E., PITTMAN J.K., HALL J.L. 2000. *Emerging mechanisms for heavy metal transport in plants*. Biochim. Biophys. Acta, 1465: 104-126.

WOJTKOWIAK K. 2014. *Systems of nitrogen fertilizing on quality of grain of spring triticale Milewo variety*. Part II. *Yield and content of nutrients.* Zesz. Probl. Post. Nauk Rol., 576: 217-226. (in Polish)

WYSZKOWSKI M. 2001. *Effect of magnesium on yield formation and the mutual relations between some ions in crops*. Wyd. UWM w Olsztynie, Rozpr. Monogr., 52, ss. 92. (in Polish).

ZEBARTH B.J., WARREN C.J., SHEARD R.W. 1992. *Influence of the rate of nitrogen fertilization on the mineral content of winter wheat in Ontario*, J. Agric. Food. Chem., 40: 1528-1530.