Agriculture (Poľnohospodárstvo), 64, 2018 (4): 183−188

Original paper

DOI: 10.2478/agri-2018-0019

SOIL AGROCHEMICAL CHANGES AFTER KIESERITE APPLICATION INTO CHERNOZEM AND ITS EFFECT ON YIELDS OF BARLEY BIOMASS

TOMÁŠ LOŠÁK[1*], JAKUB ELBL[2], ANTONÍN KINTL[2], PAVEL ČERMÁK[3], GABRIELA MÜHLBACHOVÁ[3], REINHARD W. NEUGSCHWANDTNER[4], STANISLAV TORMA[5], JAROSLAV HLUŠEK[1]

[1] Mendel University in Brno, Brno, Czech Republic
[2]Agriculture Research Ltd., Troubsko, Czech Republic
[3]Crop Research Institute in Prague, Prague, Czech Republic
[4]University of Natural Resources and Life Sciences, Vienna (BOKU), Austria
[5]National Agricultural and Food Centre – Soil Science and Conservation Research Institute, regional work place Prešov, Prešov, Slovak Republic

LOŠÁK, T. – ELBL, J. – KINTL, A. – ČERMÁK, P. – MÜHLBACHOVÁ, G. – NEUGSCHWANDTNER, R.W. – TORMA, S. – HLUŠEK, J.: Soil agrochemical changes after Kieserite application into chernozem and its effect on yields of barley biomass. Agriculture (Polnohospodárstvo), vol. *4*, 2018, no. 4, pp. 183–188.

A two-year pot experiment (5 kg of soil – Mitscherlich pots) was established in a vegetation hall in Brno (Czech Republic) in the years 2016–2017. Spring barley, variety KWS Irina, was grown. Chernozem from Brno (with a good magnesium (Mg) content and alkali soil reaction – 7.37) was used for this experiment. The rates of Mg (0.075–0.15–0.3 g per pot) and sulphur (S) (0.1–0.2–0.4 g per pot) were increased by using the ESTA Kieserite fertiliser (25% MgO; 20% S), treatments 2–4. Nitrogen was applied in the form of Calcium Ammonium Nitrate – CAN (27% N) at a rate of 1 g N per pot in all the treatments including the control. The effect of the year was found to be significant on all the parameters under study, with the exception of the soil reaction. The exchangeable soil reaction (pH) after the harvest did not differ in all the fertilised treatments (7.40–7.50) compared to the unfertilised control treatment (7.40–7.45) in both years. The content of post-harvest soil Mg and S increased significantly with the applied rate (285–354 mg Mg/kg in fertilised treatments compared to 276–284 mg Mg/kg in unfertilised control and 47–112 mg S/kg in fertilised treatments compared to 24–54 mg S/kg in unfertilised control, respectively). Dry matter yields of the aboveground biomass were significantly the lowest in the control treatment not fertilised with Mg and S during both years (23.00 and 29.02 g DM per pot) and increased after applications of Mg and S: 27.75–29.25–28.25 in 2016 and 30.33–31.00–34.50 in 2017 (g DM per pot).

Key words: magnesium, sulphur, fertilisation, soil pH, aboveground dry matter

In general, chernozem soils are regarded as very fertile soils (Živna 2010); however, to be fertile they require systematic care of the farmer, including regular and well-balanced supply of nutrients in mineral and organic fertilisers (Slowińska-Jurkiewicz *et al.* 2013).

Each crop can fully express its yield potential provided all external conditions are at optimum.

prof. Ing. Tomáš Lošák, PhD. (*Corresponding author), prof. Ing. Jaroslav Hlušek, CSc., dr. h. c., Department of Environmentalistics and Natural Resources, Faculty of Regional Development and International Studies, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic. E-mail: losak@mendelu.cz; hlusek@mendelu.cz
Ing. Jakub Elbl, PhD., Ing. Antonín Kintl, Agriculture Research Ltd., Zahradní 1, Troubsko, 664 41, Czech Republic. E-mail: jakub.elbl@mendelu.cz; kintl@vupt.cz
Dr. Ing. Pavel Čermák, Ing. Gabrieal Mühlbachová, PhD., Crop Research Institute in Prague, Drnovská 507/73, 161 06 Prague 6, Czech Republic. E-mail: pavel.cermak@vurv.cz; muhlbachova@vurv.cz
Priv.-Doz. Dipl.-Ing. Mag. Dr. Reinhard W. Neugschwandtner, Division of Agronomy, Department of Crop Sciences, University of Natural Resources and Life Sciences, Vienna (BOKU), Konrad Lorenz-Straße 24, Tulln, 3430, Austria. E-mail: reinhard.neugschwandtner@boku.ac.at
Ing. Stanislav Torma, PhD., National Agricultural and Food Centre – Soil Science and Conservation Research Institute, regional work place Prešov, Raymannova 1, 080 01 Prešov, Slovak Republic. E-mail: s.torma@vupop.sk

Harmoniuos nutrition and fertilisation are necessary components of the crop management of barley for achieving the required yields and quality (Kováčik *et al.* 2006; 2009; 2016; Neugschwandtner *et al.* 2015).

Bio-physiological functions of magnesium are well recognized, including a unique action of chlorophyll molecules in CO_2 fixation and in dry matter partition between crop organs (Shaul 2002).

Sulphur was an underestimated macroelement because of a good S supply from atmospheric deposition and wide use of S-containing fertilisers almost until the end of the 20th century (Scherer 2009). However, the content of mineral sulfur forms in soil rapidly decreased in the last three decades (Balík *et al*. 2009). Therefore, mineral sulfur deficiency starts to be an actual problem in many locations (Eriksen 2005; Lehmann *et al.* 2008; Kulhánek *et al.* 2016). Klír *et al.* (2008) went as far as to say that the uptake of S by cereals was higher (3.5 kg S/t grain + straw) than the uptake of Mg (2.3 kg Mg/t grain + straw).

The acreage of arable soil [%] in the Czech Republic in terms of Mg-supply categories is as follows: low – 17.21%, satisfactory – 34.55%, good – 32.12%, high – 8.99%, very high – 7.13%. More than 4/5 of arable land in the Czech Republic (low category – satisfactory – good) therefore requires Mg fertilisation (Smatanová & Sušil 2015).

Soil testing plays a vital part in providing field -based nutrient-management feedback to growers. To improve responses from nutrient inputs and to minimize environmental degradation, cost-effective, rapid soil tests are required to enable site-specific recommendations (Ostatek-Boczynski & Lee -Steere 2012; Mühlbachová *et al.* 2017; Čermák *et al*. 2017). Mehlich 3 method is widely used since it is capable of easily and rapidly determining the elements, phosphorus, potassium, calcium, magnesium, sodium, boron, copper, iron, manganese and zinc (Monterroso *et al.* 1999). To a certain degree the combination of soil and plant analysis and the use of calibration experiments on production sites admittedly allow the development of recommendations for Mg nutrition of crops (Gransee & Führs 2013).

As agrochemical changes in the soil after fertilisation have to be taken in consideration for developing a reasonable fertilisation regime, the objective of the study was to assess the effects of ESTA Kieserite application on both, yield of barley biomass and agrochemical changes in the soil.

T a b l e 1

Agrochemical characteristics of the soil prior to trial establishment (Mehlich III) – Regulation of Czech Republic No. 275/1998

Soil type	$pH/CaCl_2$	[mg/kg]			
		P	K	Ca	Mg
chernozem	7.37	47	226	6,081	322
	alkali	low	good	high	good

T a b l e 2

Treatments of the experiment

Treatment No.	Description	Rate of Mg [g/pot]	Rate of S [g/pot]
1	Mg_0S_0	0	0
2	Mg_1S_1	0.075	0.1
3	Mg_2S_2	0.15	0.2
4	Mg_3S_3	0.30	0.4

MATERIAL AND METHODS

The pot experiment was established on 30th March 2016 and 31st March 2017 in the outdoor vegetation hall of the Botanical Garden and Arboretum of Mendel University in Brno. In each pot, 10 seeds of spring barley (variety KWS Irina) were grown. Mitscherlich vegetation pots were filled with 5 kg of medium-textured soil, loamy (on an oven dry basis at 105ºC) characterised as Chernozem (the soil was taken from the A-horizon). Organic carbon content was 1.76%, humic acids/fulvic acid ratio was 1.04 and a humification degree was low, 14.85%.

Soil analyses were carried out before the experiment and after harvest using the Mehlich 3 method (0.015 M NH4F + 0.2 M CH3COOH + 0.25 M NH4NO3 + 0.013 M HNO3) (Mehlich 1984). The concentration of Mg and S in soil extracts was determined using ICP-OES, SPECTRO (Kleve, Germany). Table 1 gives the agrochemical properties.

Nitrogen was applied in the form of Calcium Ammonium Nitrate – CAN (27% N) at a rate of 1 g N per pot in all the treatments including the control.

The experiment involved 4 treatments given in Table 2. Every treatment included 4 repeats.

Magnesium and sulphur were applied in the form of ESTA Kieserite (25% MgO; 20% S). The pots were watered with de-mineralized water to a level of 60% of the maximal capillary capacity and were kept free of weeds. The aboveground biomass of spring barley was harvested at the stage of milk-wax maturity on 22nd June 2016 and 23rd June 2017.

The results were processed statistically using multi-way analysis of variance (ANOVA) followed by testing according to Scheffe (P = 95%).

RESULTS AND DISCUSSION

The post-harvest soil reaction (pH) and level of soil magnesium and sulphur

The optimal range of the soil reaction (pH) for barley is 6–7 (Fecenko & Ložek 2000). The exchangeable soil reaction (pH) after the harvest (Table 3) did not differ in any of the fertilised treatments (7.40–7.50) compared to the unfertilised control treatment (7.40–7.45) in both years. Every soil has its so-called buffer capacity which prevents abrupt changes in the soil reaction (also under the effect of fertilisation) and which is affected particularly by the content and quality of the humus and content of calcium and magnesium (Fecenko & Ložek 2000; Kępka *et al.* 2016). In soil used in this experiment especially the content of Ca (6,081 mg/kg) was high (on the threshold of the category very high) and buffered changes in the soil pH during vegetation. In a similar experiment but different soil – Haplic Luvisol Lošák *et al.* (2017) stated that the soil reaction (pH) increased after Mg-S fertiliser application significantly in all the fertilised treatments (6.42–6.57–6.60) compared to the unfertilised control treatment (6.10). In long-term experiments (1994–2011) on Haplic Luvisol where NPK was applied under conventional tillage and application of crop residues Šimanský & Kováčik (2015) found that the soil reaction increased by 8 to 17% compared to unfertilised control.

Depending on the selective ion uptake by plants, we divided the mineral fertilisers into physiologically acid (cation uptake prevails), alkali (anion uptake prevails) and neutral (Fecenko & Ložek 2000). Based on our results it is clear that after the application of ESTA Kieserite the soil did not change the soil reaction, however among the important factors is also the soil type and agrochemical properties of the soil. It is also commonly known that the uptake of Mg is strongly influenced by the availability of other cations like ammonium, calcium and potassium (Fageria 2001). Reverse is hence the action of Mg-Ca antagonism as the higher level of soil Mg obstructs Ca uptake by the plant and which then

T a b l e 3

The content of post-harvest exchangeable soil reaction (pH)

Treat. No.	Description	Year	
		2016	2017
1	Mg_0S_0	7.40^{aA}	7.45^{aA}
2	Mg_1S_1	7.43^{aA}	7.42^{aA}
3	Mg_2S_2	7.40^{aA}	7.45^{aA}
4	Mg_3S_3	7.42^{aA}	7.50^{aA}

Mean values of post-harvest soil pH (n = 4). The same small letters (a) indicate insignificant differences at the level of α = 0.05 among individual treatments and same uppercase letters (A) indicate insignificant differences at the level of α = 0.05 between individual years.

T a b l e 4

The content of post-harvest soil magnesium and sulphur [mg/kg]

Treatment No.	Description	Mg content		S content	
		2016	2017	2016	2017
1	Mg_0S_0	284^{aA}	276^{aB}	24^{aA}	54^{aB}
2	Mg_1S_1	309^{bA}	285^{aB}	47^{bA}	62^{bB}
3	Mg_2S_2	319^{bA}	313^{bA}	63^{cA}	82^{cB}
4	Mg_3S_3	354^{cA}	319^{bB}	102^{dA}	112^{dB}

Mean values of post-harvest soil magnesium and sulphur content (n = 4). Different small letters (a, b, c, d) indicate significant differences at the level of α = 0.05 among individual treatments and different uppercase letters (A, B) indicate significant differences at the level of α = 0.05 between the individual years.

remains in the soil in higher amounts. In chemical terms, Mg and Ca both rank among alkali earth metals with alkalifying effects on the environment. Ponette *et al*. (1993) described only very few changes in soil pH on acid soils after Kieserite application. Mengel & Kirkby (2001) noted that on more neutral soils, $MgSO_4$, e.g. Kieserite, is more appropriate particularly on arable land where application of high levels of Mg is required.

Magnesium and sulphur levels were found to differ significantly but irregularly among the treatments, Table 4. The content of post-harvest soil Mg and S increased significantly compared to the unfertilised control with the applied rate: 309–319–354 mg Mg/kg and 47–63–102 mg S/kg (2016), and 285–313–319 mg Mg/kg and 62–82–112 mg S/kg (2017), respectively. Also, Lošák *et al.* (2017) obtained similar results. The postharvest Mg and S levels were the lowest in the unfertilised control; at the same time in this treatment (treatment 1) the postharvest Mg content (284 and 276 mg/kg) was lower than at the beginning of the experiment (322 mg/kg). It is because Mg uptake by barley plants in this unfertilised control treatment (treatment 1) plus in the majority of other treatments (except treatment 4 in 2016) was not sufficiently compensated with an application of Mg fertiliser and was not rendered sufficient from mineralization of organic matter in the pot. Differences in the degree of mineralization of soil organic matter may also explain the inter-annual differences in the contents of Mg and namely S in the respective treatments. Grzebisz (2013) described that the degree of the yield increase depended on the stage of plant development and the amount of applied Mg. Cereals cultivated on soils ranging from low to medium levels of soil available Mg responded significantly to Mg applied at the rate of 5 kg/ha.

Dry matter yields of the aboveground biomass

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). Most of the literary references mention the effect of Mg application on yields and quality of barley grain in the stage of full maturity (Kováčik *et al.* 2009, 2016). However, plants in our experiment were harvested at the stage of milk-wax maturity.

The yields of the aboveground biomass (g DM/pot) are shown in Table 5 where again the effect of the year was significant. Křen *et al.* (2014) found that the formation of barley grain yield was affected by individual factors in the following or-

T a b l e 5

Dry matter yields of the aboveground biomass [g DM/pot]

Treatment No.	Description	Year	
		2016	2017
1	Mg_0S_0	23.00^{aA}	29.02^{aB}
2	Mg_1S_1	27.75^{bA}	30.33^{abB}
3	Mg_2S_2	29.25^{bA}	31.00^{bB}
4	Mg_3S_3	28.25^{bA}	34.50^{cB}

Mean values of dry matter yields of the aboveground biomass (n = 4). Different small letters (a, b) indicate significant differences at the level of α = 0.05 among individual treatments and different uppercase letters (A, B) indicate significant differences at the level of α = 0.05 between individual years.

der of importance: year, nitrogen, cultivar and sowing rate. Dry matter yields of the aboveground biomass in 2016 (Table 5) were the lowest in the control treatment (23.00 g per pot) and increased significantly after Mg-application in all the other treatments (treatments 2–4), although no significant differences were detected among these treatments. The situation was the same in 2017, however the increase in yields was significant only with the higher (treatment 3) and highest (treatment 4) Mg rate applied (31.00–34.50 g per pot), including significant differences between these treatments (3–4). In a similar experiment but different soil – Haplic Luvisol, Lošák *et al.* (2017) achieved similar results when the dry matter yields of the aboveground biomass (41.75–42.25– 44.75–44.25 g DM per pot) increased significantly only when the two highest rates of fertilisers were applied (44.75–44.25 g DM per pot) compared to the other treatments.

Based on the physiological functions of Mg it should be assumed that the shortage of Mg can result in lowering the rate of dry matter (Shaul 2002). There is some evidence that Mg plays specific roles in dry matter formation and carbon partitioning to sink organs, as under Mg deficiency carbohydrates accumulate in source leaves. Therefore, an earlier response of plants to Mg deficiency is carbohydrate accumulation in source leaves and reduced root growth due to restricted supply of the roots with carbohydrates (Cakmak *et al*. 1994).

Apart from Mg, the fertiliser ESTA Kieserite contains S which also has a positive effect on yields. Several researchers (Zhao *et al.* 2006) indicate a positive effect of S fertilisation on cereal crop production because of low soil sulphur content.

CONCLUSIONS

The results of 2-year pot experiments showed that soil applications of water-soluble Mg and S can significantly increase the Mg and S content in Chernozem, i.e., about tens of milligrams per kilogram of soil. The soil reaction (pH) did not change in any of the fertilised treatments compared to the unfertilised treatment. An adequate amount of available Mg and S in soils (in accordance with the soil test) increases the nutrient utilization efficiency which is reflected in higher biomass yields. ESTA Kieserite is a suitable mineral fertiliser for alkali soils too.

Acknowledgements. This study is a part of the project of NAZV No. QJ 1530171 called "Extension of applicability and actualization of categories for determination of the content of available macroelements and microelements in soil for ensuring the sustainability of fertility and productive capability of agricultural soils" which is financed by the Ministry of Agriculture of the Czech Republic.

We express our thanks to the staff of the Botanical Garden and Arboretum of Mendel University in Brno for their helpfulness and assistance with the experiment.

REFERENCES

BALÍK, J. – KULHÁNEK, M. – ČERNÝ, J. – SZÁKOVÁ, J. – PAVLÍKOVÁ, D. – ČERMÁK, P. 2009. Differences in soil sulfur fractions due to limitation of atmospheric deposition. In *Plant, Soil and Environment,* vol. *55*, no. 8, pp. 344–352.

CAKMAK, I. – HENGELER, C. – MARSCHNER, H. 1994. Partitioning of shoot and root dry matter and carbohydrates in bean plants suffering from phosphorus, potassium and magnesium deficiency. In *Journal of Experimental Botany*, vol. *45*, no. 9, pp. 1245–1250.

ČERMÁK, P. – PŘENOSILOVÁ, V. – MÜHLBACHOVÁ, G. – LOŠÁK, T. – HLUŠEK, J. 2017. Testing of soil properties – basic tool for rational nutrient management in agriculture. In *Journal of International Scientific Publications: Agriculture & Food,* vol. *5*, pp. 339–345.

ERIKSEN, J. 2005. Gross sulfur mineralisation-immobilisation turnover in soil amended with plant residues. In *Soil Biology and Biochemistry*, vol. *37*, no. 12, pp. 2216–2224.

FAGERIA, V.D. 2001. Nutrient interactions in crop plants. In *Journal of Plant Nutrition*, vol. *24*, no. 8, pp. 1269–1290.

FECENKO, J. – LOŽEK, O. 2000. *Výživa a hnojenie polných plodín*. SPU v Nitre a Duslo Šala, 452 p. ISBN 80-7137-777-5 (in Slovak).

GRANSEE, A. – FÜHRS, H. 2013. Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. In *Plant and Soil*, vol. *368*, no. 1–2, pp. 5–21.

GRZEBISZ, W. – PRZYGOCKA-CYNA, K. – SZCZEPANIAK, W. – DIATTA, J. – POTARZYCKI, J. 2010. Magnesium as a nutritional tool of nitrogen management – Plant production and environment. In *Journal of Elementology*, vol. *15*, no. 4, pp. 771–788.

GRZEBISZ, W. 2013. Crop response to magnesium fertilization as affected by nitrogen supply. In *Plant and Soil*, vol. *368*, no. 1–2, pp. 23–39.

KĘPKA, W. – ANTONKIEWICZ, J. – JASIEWICZ, C. – GAMBUŚ, F. – WITKOWICZ, R. 2016. The effect of municipal sewage sludge on the chemical composition of spring barley. In *Soil Science Annual*, vol. *67*, no. 3, pp. 124–130.

KLÍR, J. – KUNZOVÁ, E. – ČERMÁK, P. 2008. *The frame methodics of plant nutrition and fertilization*. Crop Research

Institute, Methodology, Praha 6 – Ruzyně, 52 p. ISBN 978-80-87011-61-4

KOVÁČIK, P. – JANČOVIČ, J. – TOMÁŠ, J. 2006. Nitrogen fertilization of spring barley at tillering stage. In *Agriculture (Polnohospodárstvo),* vol. *52*, no. 2, pp. 77–86.

KOVÁČIK, P. – JASIEWICZ, C. – WIŚNIOWSKA-KIELIAN, B. 2009. Nitrogen fertilization of spring barley at tillering stage. In *Cereal Research Communications,* vol. *37*, no. 1, pp. 237–240.

KOVÁČIK, P. – ŽOFAJOVÁ, A. – ŠIMANSKÝ, V. – HALÁSZOVÁ, K. 2016. Spring barley yield parameters after lignite, sodium humate and nitrogen utilization. In *Agriculture (Polnohospodárstvo)*, vol. *62*, no. 3, pp. 80–89. DOI: 10.1515/agri-2016-0009

KŘEN, J. – KLEM, K. – SVOBODOVÁ, I. – MÍŠA, P. – NEUDERT, L. 2014. Yield and grain quality of spring barley as affected by biomass formation at early growth stages. In *Plant, Soil and Environment*, vol. *60*, no. 5, pp. 221–227.

KULHÁNEK, M. – BALÍK, J. – ČERNÝ, J. – SEDLÁŘ, O. – VAŠÁK, F. 2016. Evaluating of soil sulfur forms changes under different fertilizing systems during long-term field experiments. In *Plant, Soil and Environment*, vol. *62*, no. 9, pp. 408–415.

LEHMANN, J. – SOLOMON, D. – ZHAO, F.J. – MCGRATH, S.P. 2008. Atmospheric SO_2 emissions since the late 1800s change organic sulfur forms in humic substance extracts of soils. In *Environmental Science and Technology*, vol. *42*, pp. 3550–3555.

LOŠÁK, T. – HLUŠEK, J. – LAMPARTOVÁ, I. – MÜHLBACHOVÁ, G. – ČERMÁK, P. 2017. Changes in the soil magnesium and Sulphur content after Kieserite application into Haplic Luvisol and the effect on yields of barley biomass. In *Acta Universitatis agriculturae et silviculturae Mendelianae Brunensis,* vol. *65*, no. 4, pp. 1225–1229.

MEHLICH, A. 1984. Mehlich 3 soil test extractant: a modification of the Mehlich 2 extractant. In *Communications in Soil Science and Plant Analysis,* vol. *15*, pp. 1409–1416.

MENGEL, K. – KIRKBY, E.A. 2001. *Principles of Plant Nutrition*. 5th Edition, Kluwer Academic Publishers, Dordrecht / Boston / London, 849 p. ISBN 978-0-7923-7150-2

MONTERROSO, C. – ALVAREZ, E. – MARCOS, M.L.F. 1999. Evaluation of Mehlich 3 reagent as a multielement extractant in mine soils. In *Land Degradation and Development*, vol. *10*, pp. 35–47.

MÜHLBACHOVÁ, G. – ČERMÁK, P. – VAVERA, R. – KÁŠ, M. – PECHOVÁ, M. – MARKOVÁ, K. – KUSÁ, H. – RŮŽEK, P. – LOŠÁK, T. – HLUŠEK, J. 2017. Boron availability and uptake under increasing phosphorus rates in a pot experiment. In *Plant, Soil and Environment,* vol. *63*, no. 11, pp. 483–490.

NEUGSCHWANDTNER, R.W. – WAGENTRISTL, H. – KAUL, H.-P. 2015. Nitrogen yield and nitrogen use of chickpea compared to pea, barley and oat in Central Europe. In *International Journal of Plan Production*, vol. *9*, no. 2, pp. 291–304.

OSTATEK-BOCZYNSKI, Z.A. – LEE-STEERE, P. 2012. Evaluation of Mehlich 3 as a universal nutrient extractant for Australian sugarcane soils. In *Communications in Soil Science and Plant Analysis*, vol. *43*, no. 4, pp. 623–630.

PONETTE, Q. – DUFEY, J. – WEISSEN, F. – van PRAAG, H.J. 1993. Downward effect of dolomite and kieserite on two acid soils differing in their organic carbon content. In *Communications in Soil Science and Plant Analysis,* vol. *24*, no. 13–14, pp. 1439–1452.

SCHERER, H.W. 2009. Sulfur in soils. In *Journal of Plant Nutrition and Soil Science*, vol. *172*, no. 3, pp. 326–335.

SHAUL, O. 2002. Magnesium transport and function in plants: the tip of the iceberg. In *BioMetals*, vol. *15*, no. 3, pp. 309–323.

SLOWIŃSKA-JURKIEWICZ, A. – BRYK, M. – MEDVEDEV, V.V. 2013. Long-term organic fertilization effect on chernozem structure. In *International Agrophysics*, vol. *27*, no. 1, pp. 81–87.

SMATANOVÁ, M. – SUŠIL, A. 2015. *Results of agrochemical testing of agricultural soils in period 2009–2014*. Central Institute for Supervising and Testing in Agriculture Brno, 106 p. ISBN 978-80-7401-114-6

ŠIMANSKÝ, V. – KOVÁČIK, P. 2015. Long-term effects of tillage and fertilization on pH and sorption parameters of haplic Luvisol. In *Journal of Elementology*, vol. *20*, no. 4, pp. 1033–1040.

ZHAO, F.J. – FORTUNE, S. – BARBOSA, V.L. – MCGRATH, S.P. – STOBART, R. – BILSBORROW, P.E. – BOOTH, E.J. – BROWN, A. – ROBSON, P. 2006. Effects of sulphur on yield and malting quality of barley. In *Journal of Cereal Science*, vol. *43*, no. 3, pp. 369–377.

ŽIVNA, T. 2010. Sledování kvality humusových látek u vybraných subtypů černozemí [Monitoring of humus substances quality at selected subtypes of Chernozems]. Bachelor thesis, Mendel University in Brno, 62 p.

Received: September 19, 2018