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EFFECT OF MAGNESIUM NUTRITION OF ONION (*Allium cepa* L.). PART I. YIELDING AND NUTRIENT STATUS

WPŁYW NAWOŻENIA MAGNEZEM CEBULI (*Allium cepa* L.) CZĘŚĆ I. PLONOWANIE I STAN ODŻYWIENIA

Abstract: Magnesium (Mg) serves specific physiological functions in plants, as it participates in 250-400 processes and may not be replaced by other elements, even those exhibiting similar physicochemical properties, such as Co^{2+} , Mn^{2+} or Ni^{2+} . The aim of the conducted studies was to optimize magnesium nutrition of onion (*Allium cepa* L.), through the evaluation of yielding of plants, and to determine its effect on contents of the following elements in leaves and bulbs: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). Magnesium was applied in the quick-acting form, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, based on the chemical analyses of soil, in doses corresponding to 50, 100, 150 and 200 $\text{mg Mg} \cdot \text{dm}^{-3}$ soil. The other nutrients were supplemented to standard levels recommended for the cultivation of onion, amounting to (in $\text{mg} \cdot \text{dm}^{-3}$ soil) 150 N, 80 P and 200 K. Magnesium nutrition was found to have a positive effect on yielding of onion and its quality. Significantly the highest total yield ($4.85 \text{ kg} \cdot \text{m}^{-2}$) and merchantable yield ($4.78 \text{ kg} \cdot \text{m}^{-2}$) were obtained when applying Mg-100, which amounted to an increase by 38% and 45% in comparison with the control combination. Plant nutrition with magnesium in case of leaves significantly affected an improvement of their nutrient status for nitrogen, deterioration of calcium nutrition, while in case of leaves and bulbs that of potassium. Analyzed levels of magnesium nutrition had a significant effect on nutrient status of leaves and bulbs for this nutrient. Leaves accumulated more nitrogen, potassium, calcium and magnesium than bulbs. Controlled magnesium nutrition of plants is an effective method of biofortification of onion with this nutrient.

Keywords: magnesium, onion, yielding, macroelements, chlorophyll

Magnesium (Mg), similarly as the other metallic nutrients, is contained in soil in 3 fractions: exchangeable, inexchangeable and water soluble [1]. The inexchangeable fraction is composed of magnesium contained in primary and secondary minerals, including those of different hydration rates [2]. In turn, the exchangeable fraction of this nutrient typically accounts for approx. 5% total magnesium content in soil and from 4 to 20% cation exchange capacity of soil. Magnesium is an important and essential macronutrient for the

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proper development and functioning of living organisms. It participates in the regulation of many biochemical processes, first of all being involved in the appropriate functioning of the brain in animals and humans. It is also a component of systemic fluids and bones. In case of plants magnesium (from 15 to 30% its total contents) is bound in chlorophyll molecules [3, 4]. It is estimated that magnesium in 75÷80% serves the function of a co-factor in many enzymatic processes, connected eg with phosphorylation, dephosphorylation, as well as hydrolysis of different compounds, and what is more it stabilizes the structure of different nucleotides [1]. Magnesium requirement of plants to a considerable degree depends on the pool of available forms of this nutrient in the soil. It usually amounts to 1 to over 20 mg Mg · 100 g soil. Magnesium is absorbed by plants in the form of the Mg^{2+} cation, but similarly as calcium (Ca), as a mobile element it may be leached, particularly in case of light soils, deeper into the soil profile by precipitation waters, which as a consequence contributes also to the consistent acidification of soil and poses a threat of insufficient nutrition of plants with this nutrient. In case of insufficient contents of magnesium in soil plants may transport this nutrient through the phloem to their actively growing, juvenile parts [1], which may result in the appearance of characteristic symptoms of magnesium interveinal chlorosis. Additional environmental factors affecting the potential occurrence of symptoms of magnesium deficit in plants include drought or irregular water availability [5, 6], low temperature [7, 8] or low pH of soil [9-11].

Garden onion (*Allium cepa* L.) is a vegetable of high economic importance. This species is grown in at least 175 countries. According to the United Nations Food and Agriculture Organization the cropped area is estimated at 2.7 million hectares and production is assessed to be 45÷55 million tons annually. The leading producers are China, India, the USA, Turkey and Pakistan [12]. Onion ranks second worldwide, after tomato, in terms of production among the 15 most important vegetable species, while it ranks 5th in Poland in terms of the level of consumption [13, 14]. Mean onion consumption per capita in Europe ranges from 7 to 8 kg, while in Poland it is 7.2 kg [15].

The aim of these studies was to optimize magnesium nutrition of onion (*Allium cepa* L.) in order to obtain the best yielding, both in terms of its quality and quantity, and to determine its effect on the contents of nitrogen, phosphorus, potassium, calcium and magnesium (in leaves and bulbs) and chlorophyll (in leaves). Biofortification of onion with magnesium is important due to the volume of consumption of this vegetable worldwide and the potential enrichment of daily diet with this nutrient.

Material and methods

The vegetation experiments were conducted in the region famous for the production of high quality field vegetable crops (central Poland). The experiments were established in the belt-row system, in four replications, on soil poor in magnesium using a heterosis onion cultivar 'Solution F₁' (Syngenta). On a bed of 135 cm in width (and 300 cm in length) there were 4 rows of plants (22.5 cm apart). Single-grain sowing was applied (in mid-April) in rows at 4 cm apart, ie 375 seeds per bed = 92.6 seeds per 1 m², which gave - at an average germinability of 85% - a density of 78.6 plants per 1 m² (ie 786 thousand plants per 1 hectare).

Prior to the establishment of the experiments soil samples were collected from the layer of the main accumulation of root systems (0÷20 cm). The collected samples of soils were

chemically analysed by the universal method of Nowosielski [16]. Extraction of macroelements (N-NH₄, N-NO₃, P, K, Ca, Mg, S-SO₄), Cl and Na was carried out in 0.03 M CH₃COOH. After extraction, N-NH₄, N-NO₃ were determined by microdistillation according to Bremner in Starck's modification, P was colorimetrically analysed with ammonium vanadomolibdate; K, Ca, Na - with the use of photometry; Mg - by atomic absorption spectrometry (AAS, on Carl Zeiss Jena - apparatus); S-SO₄ - nephelometrically with BaCl₂; Cl - nephelometrically with AgNO₃. Microelements (Fe, Mn, Zn and Cu) were extracted from soil using Lindsay's solution (containing in 10 dm³: 50 g of EDTA (*ethylenediaminetetraacetic acid*), 90 cm³ of 25% NH₄OH solution, 40 g of citric acid, 20 g of Ca(CH₃COO)₂·2H₂O) and then, they were determined by AAS method. Salination was analysed by conductometric method (electric conductivity EC in [mS·cm⁻¹]). Reaction pH was measured potentiometrically (soil : water proportion = 1:2) [17].

Mean chemical composition of soil prior to seed sowing was as follows (in [mg·dm⁻³]): N-NH₄ 4, N-NO₃ traces, P-PO₄ 36, K 38, Ca 209, Mg 12, S-SO₄ traces, Fe 55.4, Mn 18.1, Zn 3, Cu 1.55, Na 13, Cl 45; pH in H₂O 6.35, EC [mS·cm⁻¹] 0.05. Plant fertilization was developed by supplementing the nutrients found in inadequate amounts to guide values recommended for onion growing [18-20]. In the conducted experiments the control comprised the natural soil magnesium levels. In the analyzed combinations the level of magnesium in the soil was diversified, using (in [mg·dm⁻³ soil]) the amounts of 50, 100, 150 and 200 Mg (denoted as Mg-50, Mg-100, Mg-150 and Mg-200, respectively, which corresponds to magnesium doses of 10, 20, 30 and 40 g Mg·m⁻²), applying the investigated nutrient in the quick-acting form of MgSO₄·7H₂O. The other macro- and micronutrients, which constituted the background for the experiment, were supplemented to standard levels. The following were applied (in [mg·dm⁻³ soil]): 150 N in the form of ammonium nitrate in two doses (½ before sowing and the other ½ at the phase of 1-3 fully developed leaves). The other nutrients were applied once to the interrows in the early spring (in [mg·dm⁻³ soil]): 80 P as ammonium phosphate and K-200 in the form of potassium sulfate.

Towards the end of August - at the phase of harvest ripeness - a single harvest of the aboveground parts was performed and the yield of fresh weight of bulbs and the level of commercial yield were determined. Leaves and bulbs were dried at 45÷50°C and then ground. In order to assay total forms of nitrogen, phosphorus, potassium, magnesium and calcium plant material was mineralized in concentrated sulfuric acid. After mineralization of plant material the following determinations were performed: N - using the distillation method according to Kjeldahl in a Parnas-Wagner apparatus; P - by colorimetry with ammonium molybdate; K, Ca and Mg using *atomic absorption spectroscopy* (AAS); (in a Carl Zeiss Jena apparatus; Thornwood, NY, USA). The relative content of chlorophyll in leaves was measured with the use of a SPAD 506 device (by Minolta). Results of biometric measurements and chemical analyses were subjected to statistical analyses, with inference at the significance level $p = 0.05$.

Results and discussion

Yielding

Analyzed magnesium levels (in the range of Mg-50 to Mg-200) resulted in a significant increase in total and commercial yields of bulbs in relation to the control (Fig. 1). Significantly the highest total yield (4.85 kg·m⁻²) and commercial yield (4.78 kg·m⁻²) were

obtained at magnesium content in soil amounting to 100 mg Mg·dm⁻³ (Mg-100), which constituted an increase in yielding by approximately 38% and 45% in comparison with the control combination. Magnesium nutrition of onion at a dose of Mg-150 resulted in a significant reduction of total and commercial yields by 12.5% in relation to the level of Mg-100. Yielding of onion in case of magnesium nutrition levels (Mg-50, Mg-150 and Mg-200) did not differ significantly.

The optimal content of magnesium in onion growing is lower than that recorded in the analyses conducted by the authors of the study and it amounts to 50÷60 mg Mg [21]. In turn, other sources [15] reported a wider range from 50 to 80 mg Mg·dm⁻³ soil as optimal and Nowosielski [22] gave 50÷100 mg Mg dm⁻³ soil. Adamicki et al [23] proposed the range from 50 to 130 mg Mg·dm⁻³ soil, within which the results of this study exhibited a significant variation in yielding of plants. It results from the experiments conducted by the above-mentioned authors [23] that magnesium content of 130 mg Mg dm⁻³ soil contributes to a deterioration of plant yielding.

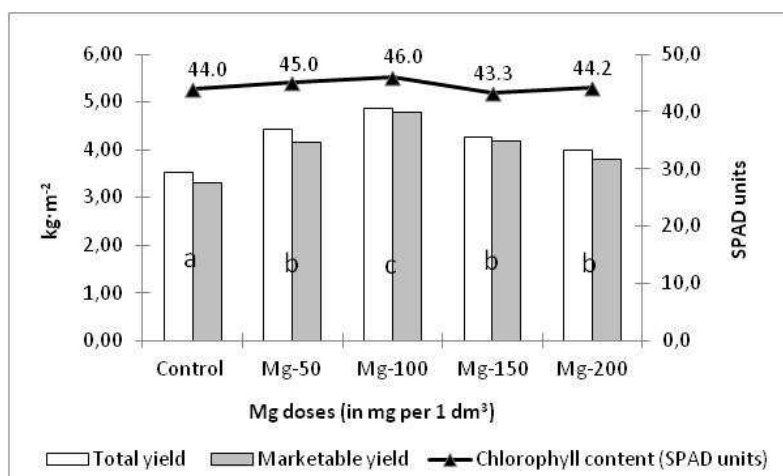


Fig. 1. The effect of plant nutrition with magnesium on total and commercial yields as well as relative chlorophyll content in leaves

Increasing the magnesium levels in soil results in an increase of contents for total chlorophyll, soluble sugars and vitamin C in leaves of garden onion and chives [24]. In the conducted analyses relative contents of chlorophyll determined in chives changed slightly under the influence of increasing magnesium nutrition of plants, falling within the range of 43.3 (Mg-150) to 46.0 (Mg-100). However, with an increase in magnesium nutrition a significant improvement was observed in the dry matter contents in leaves, which may be of importance due to the keeping quality of onion.

Chemical analyses of plants

In the conducted investigations magnesium was applied at doses ranging from 50 to 200 mg Mg·dm⁻³. Irrespective of the applied magnesium dose, mean contents of nitrogen in bulbs of onion were over two times lower than in leaves (Table 1). The highest amounts

of nitrogen were accumulated by bulbs in the Mg-50 combination, while for leaves it was in case of Mg-200, whereas in the control combination, with no magnesium fertilization, the lowest nitrogen content was determined in the above-mentioned organs. In case of phosphorus a marked synergism was found between the content of phosphorus in leaves and plant nutrition with magnesium, at the simultaneous slightly lower accumulation of phosphorus in bulbs. Mean contents of phosphorus, both in leaves and bulbs, were identical (at 0.28% P in d.m. each). In turn, a significant antagonistic effect of the increasing magnesium nutrition of plants was found on a reduction of potassium both in bulbs and leaves. Recorded contents of this nutrient in leaves were on average 2.8 times bigger than in case of bulbs. Increasing nutrition with magnesium resulted in significant changes in calcium contents both in leaves and bulbs, while in leaves its content was reduced and in bulbs (in case of Mg-100 and Mg-200) calcium content increased.

A consistent increase in the contents of magnesium, both in leaves and bulbs of onion, was found when applying magnesium in the fertilization to the level of Mg-150, but its highest dose (Mg-200) resulted in a reduction of the contents of this macronutrient in both analyzed parts of plants. On average leaves accumulated over 2.5 times more magnesium than bulbs of onion.

Magnesium is an element exhibiting multifaceted effects on the environment [25]. It modifies yielding capacity of plants, ionic equilibrium of plants as well as chemical and microbiological properties of soil. Rational fertilization with magnesium may have a positive effect on all the above-mentioned elements.

Table 1
The effect of magnesium nutrition on contents of nitrogen, phosphorus, potassium, calcium and magnesium [% in d.m.] and dry matter [% of DM]

Mg level [mg Mg·dm ⁻³]	N	P	K	Ca	Mg	[% of DM]
Leaves						
Control	2.92 a	0.24a	5.04b	3.96a	0.49a	13.3a
Mg-50	3.04 c	0.30a	5.07b	3.30b	0.54a	13.7a
Mg-100	2.99 b	0.25a	4.74a	3.16b	0.69b	14.2a
Mg-150	3.04 c	0.28a	4.79a	3.67ab	0.93c	17.5a
Mg-200	3.32 d	0.30a	4.44a	2.71c	0.77c	16.3a
Mean	3.06	0.27	4.82	3.36	0.68	15.0
Mean for Mg-50 - Mg-200	3.10	0.28	4.76	3.21	0.73	15.4
Bulbs						
Control	1.34a	0.30a	1.92b	0.62a	0.23a	15.9a
Mg-50	1.54a	0.28a	1.68a	0.57a	0.24a	15.1a
Mg-100	1.43a	0.27a	1.68a	0.72a	0.27ab	14.6a
Mg-150	1.41a	0.29a	1.70a	0.48a	0.29b	15.0a
Mg-200	1.41a	0.29a	1.64a	0.67a	0.25a	14.2a
Mean	1.43	0.29	1.72	0.61	0.26	15.0
Mean for Mg-50 - Mg-200	1.45	0.28	1.68	0.61	0.26	14.7

Values designated with the same letters in columns do not significantly differ at $p = 0.05$

Irrespective of the level of magnesium nutrition the mean contents of total nitrogen in the conducted analyses (1.41% N in d.m.) were smaller than the mean for 21 cultivars of that species (2.28% N in d.m.) analyzed by Kleiber et al [26], those of phosphorus (0.48% P in d.m.), potassium (1.95% K in d.m.) or calcium (2.00% Ca). Only in case

of magnesium the mean contents of this nutrient were higher than those reported in earlier studies [26]. Nitrogen contents found in this study in bulbs fell within the range reported earlier for the contents of this nutrient [27]. In all the analyzed combinations the contents of nitrogen in bulbs exceeded 1% N in d.m., which indicates adequate nutrition with this nutrient [28, 29], markedly higher contents of phosphorus, at the simultaneous deterioration of nutrition with potassium, calcium and magnesium [27]. Also markedly lower contents of magnesium in bulbs were reported by Tahvonen [30]. In turn, considerably lower contents of nitrogen in bulbs (on average 2.34% N in d.m.), similar for phosphorus (0.33% P in d.m.) and potassium (1.46% K in d.m.), at the simultaneous markedly worse nutrition with calcium (at average 0.13% Ca in d.m.) and magnesium (0.05% Mg in d.m.), were reported by Blazewicz-Wozniak et al [31].

The effect of magnesium in the accumulation of other nutrients is dependent on the species, plant organ and only to a slight degree on the manner of its application [25]. Literature sources report on interactions occurring between magnesium and the following elements: nitrogen [32-35], phosphorus [32, 36-39], potassium [32, 40] and calcium [41-44]. There is a positive synergistic effect of plant nutrition with magnesium on the accumulation of nitrogen in plants [45], which is confirmed by the determinations of relationships between these nutrients in case of onion leaves. In turn, magnesium and potassium as two cations acting strongly antagonistically may significantly reduce their mutual uptake by plants. This phenomenon was also documented in this study, as increasing magnesium nutrition of plants was accompanied by a significant reduction of potassium content in leaves. A similar phenomenon is observed in case of the antagonism between calcium and magnesium. In the analyses conducted by the authors of this study a significant reduction was shown for the uptake of calcium cations by leaves, with an increase in the intensity of plant nutrition with magnesium. A synergistic tendency was shown (in case of leaves) for the improvement of plant nutrition with phosphorus, occurring as a result of an improved nutrition of plants with magnesium, which confirms opinions held in this respect [32].

Conclusions

Conducted analyses aimed at the optimization of nutrition of onion (*Allium cepa* L.) with magnesium. Nutrition of plants with this nutrient had a synergistic effect on the nutrient status of leaves in case of nitrogen and phosphorus, a deterioration of calcium nutrition of leaves and that of leaves and bulbs with potassium. Analyzed levels of magnesium nutrition significantly modified contents of this nutrient in leaves and bulbs. Leaves accumulated more (means in [%]) N - 114, K - 180.2, Ca - 450.8 and Mg - 161.5 than bulbs. Increasing magnesium nutrition levels did not have a significant effect on relative contents of chlorophyll in leaves. A positive effect of the analyzed nutrient was found on yielding of onion and its quality. Significantly highest total and commercial yields were obtained when using 100 mg Mg·dm⁻³ soil, which constituted an increase by 38% and 45% in comparison with the control combination. The best yielding of plants was obtained at the following contents of nutrients in leaves (in [% in d.m.]): N 2.99, P 0.25, K 4.74, Ca 3.16, Mg 0.69 and in bulbs (in [% in d.m.]): N 1.43, P 0.27, K 1.68, Ca 0.72 and Mg 0.27. These contents are proposed as guide values for onion. Controlled magnesium nutrition of plants is an effective method of biofortification of onion with this nutrient.

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WPŁYW NAWOŻENIA MAGNEZEM CEBULI (*Allium cepa* L.) CZĘŚĆ I. PLONOWANIE I STAN ODŻYWIENIA

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Abstrakt: Magnez (Mg) pełni w roślinie specyficzne funkcje fizjologiczne - bierze udział w 250-400 procesach i nie może być zastąpiony przez inne pierwiastki, nawet o zbliżonych właściwościach fizykochemicznych, takie jak Co²⁺, Mn²⁺ czy Ni²⁺. Celem prowadzonych badań była optymalizacja żywienia cebuli (*Allium cepa* L.) magnezem poprzez ocenę plonowania roślin oraz jego wpływu na zawartość w liściach i cebulach: azotu (N), fosforu (P), potasu (K), wapnia (Ca) i magnezu (Mg). Magnez zastosowano w formie szybko działającego MgSO₄·7H₂O, na podstawie analizy chemicznej gleby, w dawkach odpowiadających: 50, 100, 150, 200 mg Mg·dm⁻³ gleby. Pozostałe składniki pokarmowe uzupełniano do poziomów standardowych polecanych do

uprawy cebuli wynoszących (w $\text{mg}\cdot\text{dm}^{-3}$ gleby): 150 N, 80 P, 200 K. Stwierdzono pozytywny wpływ żywienia magnezem na plonowanie cebuli oraz jej jakość. Istotnie największy plon ogólny ($4,85 \text{ kg}\cdot\text{m}^{-2}$) oraz handlowy ($4,78 \text{ kg}\cdot\text{m}^{-2}$) uzyskano, stosując Mg-100, co stanowiło wzrost o 38% i 45% w porównaniu z kombinacją kontrolną. Żywienie roślin magnezem wpływało istotnie w przypadku liści na poprawę stanu ich odżywienia azotem, pogorszenie odżywienia wapniem - a w przypadku liści i cebuli - potasem. Badane poziomy żywienia magnezem wpływały istotnie na stan odżywienia liści i cebuli tym składnikiem. Liście gromadziły więcej azotu, potasu, wapnia i magnezu niż cebula. Kontrolowane żywienie roślin magnezem jest efektywną metodą biofortyfikacji cebuli w ten składnik.

Słowa kluczowe: magnez, cebula, plonowanie, makroelementy, chlorofil