# CONCENTRATION OF MAGNESIUM AND ITS UPTAKE BY ABOVEGROUND PHYTOMASS OF SPRING BARLEY *(HORDEUM VULGARE* L.*)* GROWN UNDER DROUGHT STRESS CONDITION

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***Abstract:*** *The aim of this contribution was to evaluate the effect of drought stress on the content of magnesium in aboveground phytomass dry mater of spring barley in main growth stages of growing season and its uptake by aboveground biomass. At the same time the anti-stress effect of applied fertilizer nitrogen was investigated. Lower concentration of magnesium in stressed plants in comparison to optimum water regime in various treatments of nutrition can reduce photosynthesis performance and strongly deteriorate grain formation. It is important to overcome at least partially the effect of drought stress by soil fertility increasing. One of the possibilities is to apply nitrogenous fertilizers which can alleviate the adverse effect of drought in dry periods of changing climate. Effect of nitrogen rates (1.0 g, 2.0 g N per pot) on magnesium concentration and uptake of Mg by aboveground phytomass of spring barley (variety Kompakt) and grain yield was investigated in 3-year pot experiment. Plants were grown under optimum moisture regime (60% of full soil water retention capacity) and drought stress (15-20% of full soil water retention capacity) was induced during growth stage of tillering, shooting and earing, respectively. Before and after respective stress period the plants were grown under optimal water regime.Ageing of the plant cover caused a decrease of Mg concentration in dry matter of aboveground phytomass. Fertilization of barley by nitrogen reduced the magnesium concentration in dry matter in all investigated growth stages (except 1 g N at tillering) at optimum water regime in comparison with unfertilized control treatment. Under stress conditions the situation was quite different and N fertilization tended to increase Mg concentration in dry matter. In opposition to Mg concentration, uptake of Mg by aboveground phytomass was increasing by ageing of plant cover in both fertilized and unfertilized treatments with maximum in growth stage of earing. Fertilization with nitrogen increased amount of up-taken magnesium several times comparing to control treatment under optimum water regime. Drought stress adversaly influenced Mg uptake, especially in fertilized treatment, where it decreased by 25-50% in comparison to uptake by plants grown under optimal water regime.*

***Key words*****:** *drought stress, nitrogen nutrition, growth stages, magnesium concentration, uptake of magnesium*

## INTRODUCTION

Water deficit influences existence of plant in broad spectrum of processes. The most sensitive plant organs reacting to water stress are the leaves in which water potential drops (PROCHÁZKA, 2003). When water potential declines, it evokes reduction of cell division, closing of stomata due to effect of abscisic acid and inhibition of net assimilation (TAIZ and ZEIGER, 2002). At water potential decrease bellow -1 MPa the formation of proline increases and it functions as protective mechanism of membranes and as osmoticum at the same time (BRESTIČ and OLŠOVSKÁ, 2001).

SAINI and VESTGATE (2000) found out that water deficit can strongly deteriorate grain formation, germination of pollen, fertility of embryos and prematuraly finish grain development. In general, cereals are the most sensitive to water deficit in growth stage of earing and flowering. Yield can be reduced with induced drought by 5-30% in dependence on water stress duration in the growth stage of earing (SLAFER et al., 2002).

In case that water availability during flowering is low the yield declines due to grain sterility as well as worse mobility of nutrients into grain (PASSIOURA, 2002), fig. 1.

To overcome at least partially the effect of drought stress, some measures have been suggested. By increasing soil fertility, especially with nitrogenous fertilizers the adverse effect of drought can be alleviated substantially (LAHIRI, 1980; WANG et al., 2003). Nitrogen nutrition exhibits positive effect on the nitrogen metabolism adaptation in drought conditions (WANG et al., 2003; KRČEK et al. 2005).

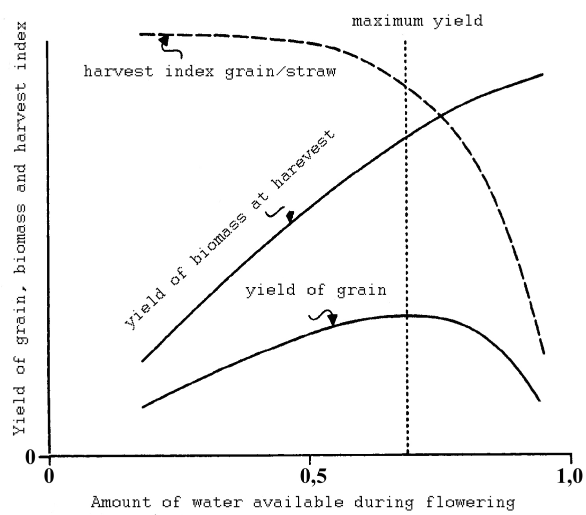


Figure 1: Changes in grain yields, total biomass and harvest index in dependence on water availability during flowering (PASSIOURA, 2002)

Uptake of magnesium by plant is carried out passively on the basis of electrochemical gradient. Antagonistic effect on magnesium uptake was shown by $K^+$, $Ca^{2+}$, $NH_4^+$. In contrary, synergic effect was determined with $NO_3^-$ (MENGEL and KIRKBY, 1987; BERGMAN and ČUMAKOV, 1977; VANĚK et al., 2007).

MARSCHNER (2003) states that 6-25% of total plant Mg is located in chlorophyll, 5-10% in pectates of medium lamellae and rest 65-90% in vacuole. From the biochemical point of view, magnesium participates in activation of many enzymes, for instance phosphoenol pyruvate (PEP), carboxylase (WEDDING and BLACK, 1988), glutathion synthetase (MARSCHNER, 2003), phosphatases, kinases, carboxylases etc.

Under the magnesium deficit similar symptons appear as under oxidative stress conditions. In leaves concentration of $O_2^{2-}$ ($H_2O_2$) increases as well as activity of antioxidants does: ascorbase, superoxid dismutase (CAKMAK and MARSCHNER, 1992).

On the other side higher rates of magnesium applied in conditions limiting plant growth (stress) cause increase of magnesium storage in vacuole. Here magnesium plays the role of buffer as well as the factor insuring metabolic pool homeostasis maintenance; and is also important in charge compensation and vacuole osmoregulation.

High content of magnesium in leaves (more than 1.5%) can be critical especially under drought conditions. Under the decrease of sunflower leaves water potential, concentration of magnesium in cells increases from 3-5 mM to 8-13 mM. Increased Mg concentration adversally affects stroma of chloroplasts, phosphorylation and photosynthesis (RAO et al., 1987). KAISER (1987) confirmed that magnesium concentration in chloroplasts increases up to the level of 24 mm under water stress conditions.

During tillering and shooting content of magnesium in dry mater of aboveground phytomass should fluctuate within the range of 0.20-0.25%.

FECENKO and LOŽEK (2000) state that deficit of magnesium inhibits nitrate reductase which metabolises $NO_3^-$ in plants by what the plant products are of higher quality from the view point of nitrates content.

It was proved that nitrate reductase inactivation is related to phosphorylation because an increase of Mg ATP concentration under in vitro conditions inactivates nitrate reductase (Morot-Gaudry et al., 2001), and in opposition, ADP enables reactivation of nitrate reductase (NR). From this reason it can be supposed that magnesium in plants ensures regulation of NR and its deficit can cause serious disorders in $NO_3^-$ assimilation.

The aim of this contribution was to evaluate the effect of drought stress on the content of magnesium in aboveground phytomass dry mater of spring barley in main growth stages of growing season and its uptake by aboveground biomass. At the same time the anti-stress effect of applied fertilizer nitrogen was investigated.

## MATERIAL AND METHODS

Effect of water stress and nitrogen rates on Mg concentration in aboveground phytomass and Mg uptake by aboveground phytomass of spring barley (variety Kompakt) was investigated in pot vegetation experiment at atmospheric conditions during growing seasons 2005, 2006 and 2007. Individual pots were fulfilled with 16 kg of sieved soil (Haplic – Luvisols) with the agrochemical characteristics as they are stated in Table 1. Contents of P, K, Ca and Mg in used soil were dermined by Mehlich II method and mineral nitrogen ($N_{min}$) as the sum of $NH_4^+$-N (colorimetrically by Nessler agent) and $NO_3^-$-N (colorimetrically by 2, 4-disulphonic acid) after previous soil extraction in 1% $K_2SO_4$. There were applied the following rates of N per pot: 0.0 g (treatment 1 - control), 1.0 g (treatment 2), 2.0 g (treatment 3) in the form of liquid N-fertilizer DAM – 390. Originally there were sown 32 grains into surface soil layer of each pot and 7 days after emerging the seedlings were thinned for 22 most vigorous and approximatelly equal plants. Each treatment was 4 times repeated. The plants were grown within two blocks at the same nutrition treatments. Plants in the first block were grown under optimum soil moisture regime (60% of full soil water retention capacity – FSWRC) during the whole growing season; and in the second block drought stress was applied on plants during the duration of growth stage of tillering, shooting and earing, respectively. During respective stress period soil water content in pots was maintained on the average level of 15-20% of FSWRC. Before and after respective stress period the plants were grown under optimum water regime until the end of growing season (Fig. 2).

*Table 1*

Agrochemical characteristics of soil before experiment establishment

| Year | $N_{an}$ | P | K | Ca | Mg | $pH_{KCl}$ |
|---|---|---|---|---|---|---|
| | mg $kg^{-1}$ | | | | | |
| 2005 | 11.3 | 44.0 | 224.0 | 2 026 | 448 | 5..90 |
| 2006 | 16.6 | 24.2 | 248.4 | 2 051 | 307 | 5.90 |
| 2007 | 17.0 | 55.0 | 335.0 | 2 000 | 325 | 5.75 |

$N_{an} = N_{min =}$ mineral nitrogen

Content of Mg in plants was determined by atomic absorption spectrophotometry in the following growth stages: end of tillering (DC 29), end of shooting (DC 49), end of

flowering (DC 69). Concentration of Mg was expressed as % in dry matter and magnesium uptake by aboveground phytomass of spring barley was calculated per hectare (kg $ha^{-1}$).
The achieved results were treated statistically by analysis of variance at significance level of 0.05. Differences between the levels of investigated experimental factors were tested by LSD procedure.

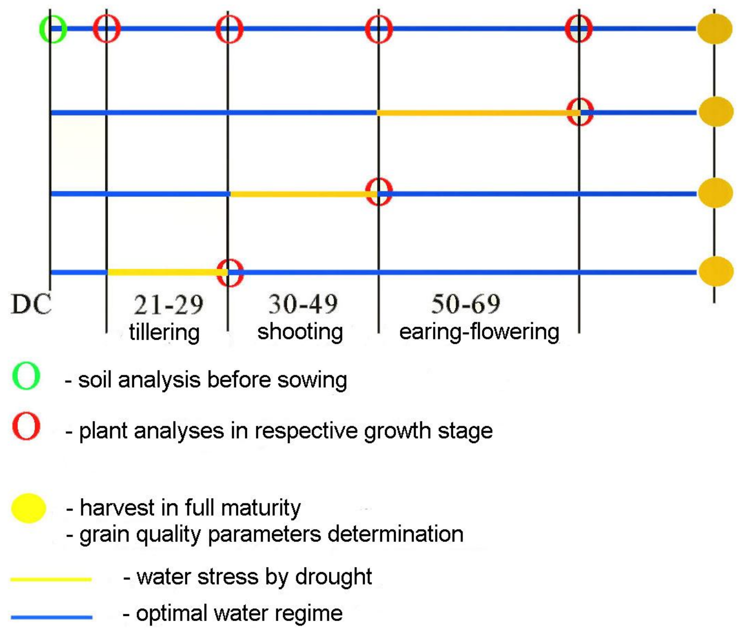


Figure 2: Design of water stress induction in the experiment

**RESULTS AND DISCUSSIONS**

Concentration of magnesium in dry mater (DM) of spring barley aboveground phytomass was significantly higher in optimally watered treatments than in adequate treatments of barley grown under drought stress conditions (fig. 3, tab. 2). This result is in harmony with HU et al. (2008) who investigated effect of water stress on Mg concentration in the 3$^{rd}$ leave of maize under various treatments of nutrition. The authors confirmed lower concentration of magnesium in the 3$^{rd}$ leave of maize on the stressed treatments in comparison to optimum water regime in all treatments of nutrition.

On the average of years and nitrogen rates higher Mg concentration in DM of aboveground phytomass was determined in the growth stage of shootingcompared to growth stage of tillering when under stress conditions this increase was statistically significant (tab. 3, fig. 3). Further ageing of barley plants caused, probably as a consequence of dilution effect, statistically significant decrease of magnesium concentration in DM at both levels of water regime. Similar findings were also published by BENČÍKOVÁ (2009) based on the results of small-plot experiment with winter barley. Effect of nitrogen fertilization in growth stage of tillering and shooting was negligible and Mg concentration was changing only slightly within the range of 1-2 hundereds of percentage in optimally watered plants.

More expressive change in Mg concentration was analyzed in growth stage of earing, especially at the rate 1g N per pot, when Mg concentration decreased from 0.20% (unfertilized control) to 0.16% (1g N per pot) in DM.

Fertilization with nitrogen, particularly the rate of 2g N per pot, increased Mg concentration in DM of barley aboveground phytomass when it was grown under stress conditions (fig. 3). Nitrogen rate of 1g per pot was less effective in growth stage of earing resulting in decline of Mg DM concentration to 0.16% from initial 0.18% (unfertilized control).

*Table 2*

Influence of experimental factors on the concentration and uptake of Mg within the whole experiment (LSD test)

| Source of variability | Frequency (n) | Level of factor | Con. of Mg (% DM) | Uptake of Mg (kg ha$^{-1}$) |
|---|---|---|---|---|
| | | | Average | |
| Rate of nitrogen | 72 | 0 g | 0.1998 a | 1.4800 c |
| | | 1 g | 0.1829 b | 5.6019 b |
| | | 2 g | 0.2097 a | 6.7759 a |
| LSD (0.05) | | | 0.0117 | 0.3769 |
| Growth stage | 72 | tillering | 0.1996 b | 1.9136 c |
| | | shooting | 0.2139 a | 4.9767 b |
| | | earing | 0.1790 c | 6.9676 a |
| LSD (0.05) | | | 0.0117 | 0.3769 |
| Water regime | 108 | optimal | 0.2056 a | 5.4778 a |
| | | stressful | 0.1894 b | 3.7608 b |
| LSD (0.05) | | | 0.0096 | 0.3078 |

LSD-the least significant difference

Note: The same letters at averages of values indicate statistically insignificant difference

As far as the uptake of magnesium by aboveground phytomass is concerned, the lowest values were calculated in unfertilized treatments at both levels of water regime in soil; and fluctuated within the interval 0.7-2.30 kg ha$^{-1}$ Mg (fig. 3). Uptake of magnesium was considerably dynamized by nitrogen fertilization, mainly through the increasing yields of aboveground phytomass. Nitrogen fertilization was more effective in optimally watered treatments in which uptake of Mg by plants was several times higher and statistically significant (tab. 2, 3) in comparison with unfertilized treatment (fig. 3); and approximately 1.5-2 times higher than uptake by plants which were exposed to stress in certain growth stage of growing season. WHEELER and EDMEADES (1995) state that nitrate increased the uptake of Mg by wheat plants, whereas ammonium did not increase Mg uptake as much.

As to nitrogen rate, the rate of 2g per pot was more effective in Mg uptake by aboveground phytomass of spring barley than half rate of nitrogen under both exemined water regimes.

The values of Mg uptake in moistured and fertilized treatments fluctuated in the range from 2.8 to 12.6 kg ha$^{-1}$; under stressed and fertilized conditions it was within the interval 1.80-8.20 kg ha$^{-1}$. Uptake of Mg by aboveground phytomass of spring barley was increasing significantly by ageing of barley cover; and achieved values of uptake are in accordance with the results published by BENČÍKOVÁ (2009) for maximum winter barley magnesium uptake (7.9-8.9 kg ha$^{-1}$) obtained in the growth stage of earing.

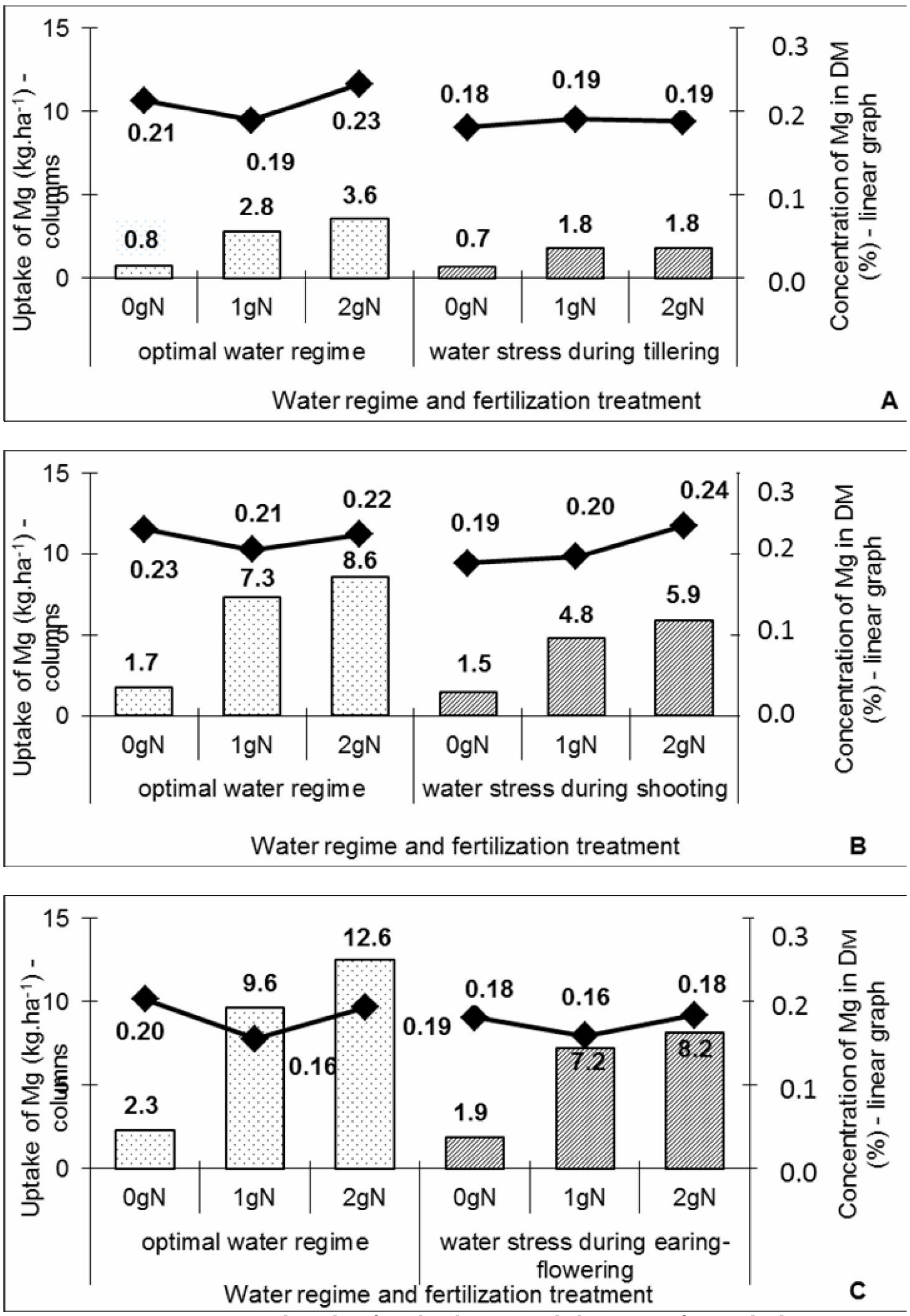

Figure 3: Concentration and uptake of Mg by aboveground phytomass of spring barley grown under N-fertilized water optimum and drought stress conditions

*Table 3*

Influence of experimental factors on the concentration and uptake of Mg under optimal and stress water regime, LSD test (average of growth stage/fertilization, years and repetitions; n=36)

| Source of variability | Level of factor | Optimal water regime | | Drought stress | |
|---|---|---|---|---|---|
| | | Con. of Mg (% DM) | Uptake of Mg (kg ha$^{-1}$) | Con. of Mg (% DM) | Uptake of Mg (kg ha$^{-1}$) |
| | | average | | | |
| Rate of nitrogen | 0 g | 0.2161 a | 1.5967 c | 0.1836 b | 1.3633 c |
| | 1 g | 0.1836 b | 6.5789 b | 0.1822 b | 4.6250 b |
| | 2 g | 0.2169 a | 8.2578 a | 0.2025 a | 5.2942 a |
| Growth stage | tillering | 0.2122 a | 2.3858 c | 0.1869 b | 1.4414 c |
| | shooting | 0.2206 a | 5.8903 b | 0.2072 a | 4.0631 b |
| | earing | 0.1839 b | 8.1572 a | 0.1742 b | 5.7781 a |
| LSD (0.05) | | 0.0168 | 0.5433 | 0.0145 | 0.4551 |

Note: Explanations are the same as below the table 2

## CONCLUSIONS

Higher rate of nitrogen (2g per pot) increased magnesium concentration in dry mater of barley aboveground phytomass when barley was grown under drought stress conditions. In optimally watered plants the effect of nitrogen fertilization was negligible in growth stage of tillering and shooting in oposition to growth stage of earing where Mg concentration decreased from 0.20% (unfertilized control) to 0.16% (1g N per pot) in DM. Concentration of Mg in DM of spring barley aboveground phytomass was significantly higher under optimal water regime than in drought stress conditions.

Uptake of Mg by aboveground phytomass was the lowest in unfertilized treatments under both levels of water regime. Nitrogen fertilization dynamized uptake of Mg by plants. Nitrogen fertilization exhibited more expressive effect on Mg uptake by plants which were grown under optimal water conditions.

Under such conditions uptake of Mg was several times higher in comparison with unfertilized control treatment; and approximately 1.5-2 times higher than uptake by plants exposed to drought stress in certain growth stage of growing season.

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