Effect of Magnesium Treatment on the Production of Hydroponic Lettuce

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***Abstract*—The species of lettuces are grown in extraordinary wide variety, nowadays. Hydroponic lettuce growing, make possible continuous cultivation of lettuce all the year. Lettuce is an economically very important vegetable. When grown in a glasshouse, in hydroponics the vegetation cycle is shorter (2 months), because the environmental factors (e.g. climate) are not affecting the culture, the presence of pests and diseases can be excluded, bigger crop yields can be achieved, so this is more profitable. In the course of the experiment, the following doses of magnesium were added to the standard nutriment solution: 50-, 100-, 150-, 200- and 250 mg l^{-1}. The magnesium supplements were added in the form of $Mg(NO_3)_2$ solution in our experiment. The treatments were carried out with 4 repetitions in randomized block design.**

***Index Terms*—magnesium treatment, hydroponic, lettuce, greenhouse**

I. Introduction

Lettuce became from a seasonal vegetable into an all-year grown food having a wide range of species. Modern technologies, by using hydroponic lettuce growing, permit continuous cultivation of lettuce for 12 months every year [1], [2]. The average consumption of the plant increased during the previous decade, so it can be inserted into modern healthy nourishment. Lettuce (*Lactuca sativa* convar. *capitata* L.) is a significant vegetable, rich in vitamins and minerals as well. Growing in hydroculture has several beneficial advantages compared to the soil growing as regard of: faster development, higher average of yield, balanced and schemed development. Furthermore, growing can be automated by electric technologies, in an environmentally friendly way, and the production does not require significant manual labour [3], [4].

By the use of an automated (electronic technology) system, the nutrient solution can circulate several times a day in the hydroculture channel system [5]-[14].

Magnesium is a central component of chlorophyll, which has a unique role in photosynthesis; magnesium is an essential metal in the plant metabolism, protein biosynthesis, and collaborates as a metallic catalyst in take and release of energy [15]-[19].

The aim of this research was to determine the optimal nutrient concentration of magnesium and to quantify the proper fertilizer concentration for hydroponic lettuce (*Lactuca sativa* convar. *capitata* L.) cultivation in the aspect of biomass production.

II. Materials and Methods

Our hydroponic experiment was conducted in the greenhouse of the Faculty of Horticulture and Rural Development, at the Pallasz Athéné University (in Kecskemét, in Hungary) from 2014 to 2016. The plants were placed into stone wool (grodane), where the submersible pump provided proper moisture and nutrients to the roots. During the course of the experiment, the magnesium supplements were added in the form of $Mg(NO_3)_2$ The following doses of magnesium were added to the standard nutriment solution in our experiment: 50-, 100-, 150-, 200- and 250 mg l^{-1} Mg solution. In the control treatment plants were grown with the use of standard nutriment solution without magnesium supplement.

The necessary nutrient solution was made from the following water-soluble fertilizers: 666.7 g Ferticare komplex (N 14%, P_2O_5 11%, K_2O 25%); 733.3 g $Ca(NO_3)_2$ (N 15%, CaO 26%); 66.7 g KH_2PO_4 (P_2O_5 54%, K_2O 32%); 100 ml 60 m V%$^{-1}$ H_3PO_4 added to 1000 liters of water.

Figure 1. The 28 liters tank.

We filled the hydroponic tanks of 28 liters (Fig. 1) with a new nutrient solution every week. Only highly soluble fertilizers were used. In the hydroponic production watering with the nutrient solution was done

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using an automated pump system, three times a day in autumn and five times a day in spring for 15 minutes. On the main switch (Fig. 2) we configured when the submersible pump (Fig. 3) should be active. The circulation of the nutrient solution started in autumn at 9 a.m., at 12 a.m. and at 3 p.m. The circulation of the nutrient solution started in spring at 8 a.m., at 10 a.m., at 12 a.m., at 2 p.m. and at 4 p.m.

Figure 2. The main switch of the automated system.

Figure 3. The submersible pump.

Figure 4. The gravity cup.

The nutrient solution was pumped into the gravity cup (Fig. 4), then with the help of gravity it got into the channel through the pipe network.

Experimental plants were propagated by seeding and subsequent transplant raising in greenhouse. The lettuce seedlings were placed into rock cotton cubes, and put into hydroponic growing channels. Table I summarises the lettuce seedlings dates.

TABLE I. THE LETTUCE SEEDLINGS

Year	Date of autumn seedlings	Date of spring seedling
2014	7^{th} September	-
2015	24^{th} August	20^{th} February
2016	-	22^{nd} February

Each channel of the closed nutrient system had a separate container with a separate submersible pump to ensure adequate circulation of the nutrient solution for plants. The number of plants per plot was 28. The experimental design was a randomized blocks with 4 repetitions. In each treatment 7 plants were measured.

TABLE II. THE LETTUCE HARVEST

Year	Date of autumn harvest	Date of spring harvest
2014	14^{th} November	-
2015	29^{th} October	5^{th} May
2016	-	4^{th} May

Electrical conductivity in nutrient solutions was measured by laboratory EC-meter (type ORION 3Star) in both year, in two repetitions (in two growing channels), respectively.

The statistical analysis was accomplished with SPSS v19 software. The mean difference is significant at the 0.05 level [20]. Following harvest (Table II), the leaves of lettuce were dried in a LTE-OP-250 drying oven in the laboratory. In the course of the experiment, the nutrient element concentrations nitrogen, magnesium and calcium were determined in the leaves of lettuce.

III. RESULTS

The lettuce grew at a proper rate in the stone wool. The leaves turned yellow and brown when using solutions of higher concentration. For our statistics calculations we compared the growth of the Mg-treated lettuce to that of the control plants. The development of the lettuce head weight is shown in Table III in 2014 autumn, and in Table IV in 2015 autumn.

TABLE III. LETTUCE HEAD WEIGHT (G) IN 2014 AUTUMN

Treatments	N	Mean (g)	St. Dev.	St. Error	Min. (g)	Max. (g)
Control	28	291.1	19.719	3.727	253	320
50 mg l^{-1} Mg	28	236.2	29.610	5.596	167	286
100 mg l^{-1} Mg	28	262.0	20.661	3.905	222	324
150 mg l^{-1} Mg	28	215.6	32.266	6.098	168	275
200 mg l^{-1} Mg	28	223.1	23.973	4.531	188	261
250 mg l^{-1} Mg	28	213.7	26.362	4.982	178	268
Total	**168**	**240.3**	**37.841**	**2.919**	**167**	**324**

TABLE IV. LETTUCE HEAD WEIGHT (G) IN 2015 AUTUMN

Treatments	N	Mean (g)	St. Dev.	St. Error	Min. (g)	Max. (g)
Control	28	186.1	26.118	4.936	140	240
50 mg l^{-1} Mg	28	132.3	13.709	2.591	115	160
100 mg l^{-1} Mg	28	131.4	35.009	6.616	80	210
150 mg l^{-1} Mg	28	111.6	17.902	3.383	85	155
200 mg l^{-1} Mg	28	117.1	22.748	4.299	65	170
250 mg l^{-1} Mg	28	104.1	18.056	3.412	65	130
Total	**168**	**130.5**	**35.384**	**2.730**	**65**	**240**

We measured 28 plants from each treatment area. The minimum and maximum mass can be found in Table III and Table IV. The maximum weight was found in the control group, while the minimum was among the 250 mg l^{-1} and 150 mg l^{-1} magnesium treatments.

Tukey statistical analysis were summarise in Table V (in 2014 autumn) and Table VI (in 2015 autumn).

TABLE V. TUKEY HSD TEST OF LETTUCE (PARAMETER: LETTUCE HEAD WEIGHT) IN 2014 AUTUMN

Treatments (A)	Treatments (B)	Mean difference (A-B)	St. Error	Significance level
Control	50 mg l^{-1} Mg	54.89 *	6.904	0.000
	100 mg l^{-1} Mg	29.11 *	6.904	0.001
	150 mg l^{-1} Mg	75.46 *	6.904	0.000
	200 mg l^{-1} Mg	67.96 *	6.904	0.000
	250 mg l^{-1} Mg	77.43 *	6.904	0.000

*The mean difference is significant at the 0.05 level.
n.s. = not significant

TABLE VI. TUKEY HSD TEST OF LETTUCE (PARAMETER: LETTUCE HEAD WEIGHT) IN 2015 AUTUMN

Treatments (A)	Treatments (B)	Mean difference (A-B)	St. Error	Significance level
Control	50 mg l^{-1} Mg	54.89 *	6.904	0.000
	100 mg l^{-1} Mg	29.11 *	6.904	0.001
	150 mg l^{-1} Mg	75.46 *	6.904	0.000
	200 mg l^{-1} Mg	67.96 *	6.904	0.000
	250 mg l^{-1} Mg	77.43 *	6.904	0.000

* The mean difference is significant at the 0.05 level.
n.s. = not significant

Every treatments (50-, 100-, 150-, 200- and 250 mg l^{-1}) was significant at the 0.05 level in both 2014 and 2015 autumns.

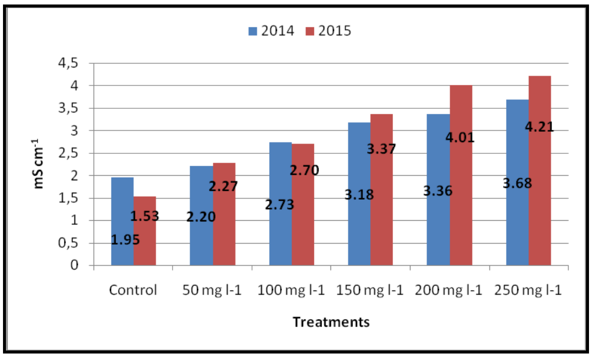

Figure 5. EC of the nutrient solutions in the treatment groups (repetition I. in 2014 and 2015 autumn).

We took samples from the hydroponic tanks to test their EC. Changes in the electric conductivity are shown in Fig. 5 and Fig. 6. The control had the lowest EC values in repetition I. (1.95 and 1.53 mS cm^{-1}) and repetition II. (2.05 and 1.49 mS cm^{-1}) in both year. The 250 mg l^{-1} Mg treatment had the highest EC values in both repetitions (3.68 and 4.21 mS cm^{-1}) and the II: repetition (4.00 and 4.61 mS cm^{-1}). The EC values increased along with the magnesium concentration.

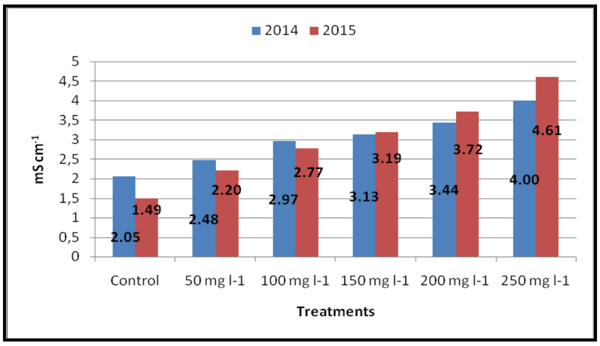

Figure 6. EC of the nutrient solutions in the treatment groups (repetition II. in 2014 and 2015 autumn).

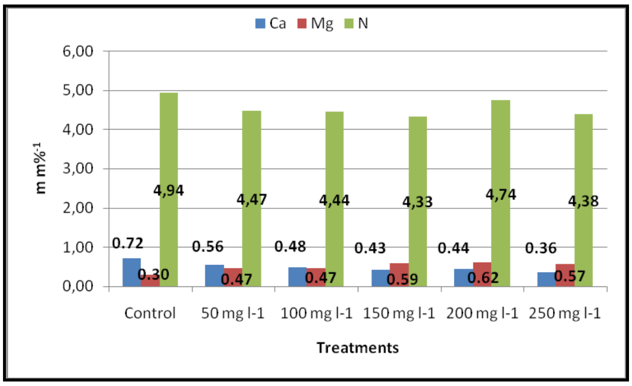

Figure 7. The nutrient element concentration (N, Mg, Ca) in the leaves of lettuce (2014 autumn).

In the course of the experiment, the nutrient element concentrations nitrogen, magnesium and calcium were determined in the leaves of lettuce (Fig. 7 and Fig. 8).

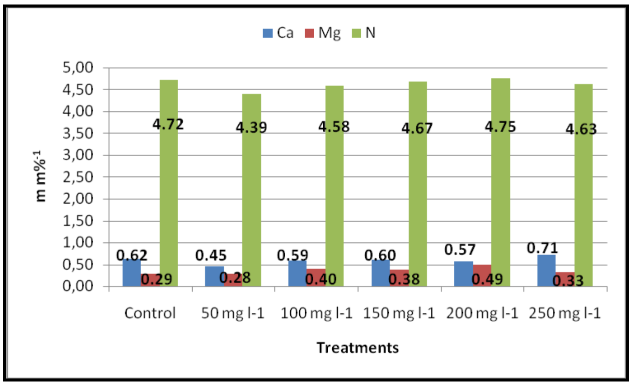

Figure 8. The nutrient element concentration (N, Mg, Ca) in the leaves of lettuce (2015 autumn).

The increasing magnesium concentration in the nutriment solution caused the decrease of nitrogen content of dry matter in the leaves from 4.94 m m^{-1} % to 4.38 m m^{-1} % in 2014. The next year, in 2015 was also decrease from 4.72 m m^{-1} % to 4.63 m m^{-1} %. The concentration of magnesium increased in 2014 (from 0.30 m m^{-1} % to 0.62 m m^{-1} %) and in 2015 (from 0.29 m m^{-1} % to 0.49 m m^{-1} %). The concentration of calcium decreased in 2014 (from 0.72 m m^{-1} % to 0.36 m m^{-1} %) and 2015 (from 0.62 m m^{-1} % to 0.71 m m^{-1} %), in the average of repetitions.

Table VII and Table VIII summarize the lettuce head weight in 2015 and 2016 spring. As expected and shown by the analysis of variance, as well as Tukey HSD test (Table IX and Table X), the growth parameters show significantly different values for lettuce head weight.

TABLE VII. LETTUCE HEAD WEIGHT (G) IN 2015 SPRING

Treatments	N	Mean (g)	St. Dev.	St. Error	Min. (g)	Max. (g)
Control	28	16.5	34.102	6.445	0	116
50 mg l^{-1} Mg	28	23.5	16.787	3.173	0	53
100 mg l^{-1} Mg	28	28.8	43.198	8.164	0	110
150 mg l^{-1} Mg	28	78.8	25.853	4.886	40	128
200 mg l^{-1} Mg	28	95.4	28.867	5.455	61	177
250 mg l^{-1} Mg	28	86.6	15.711	2.969	53	118
Total	**168**	**54.9**	**43.397**	**3.348**	**0**	**177**

TABLE VIII. LETTUCE HEAD WEIGHT (G) IN 2016 SPRING

Treatments	N	Mean (g)	St. Dev.	St. Error	Min. (g)	Max. (g)
Control	28	209.5	41.765	7.893	141	289
50 mg l^{-1} Mg	28	173.8	40.462	7.647	115	250
100 mg l^{-1} Mg	28	177.3	46.723	8.830	121	267
150 mg l^{-1} Mg	28	206.5	32.012	6.050	174	297
200 mg l^{-1} Mg	28	198.1	30.683	5.798	148	259
250 mg l^{-1} Mg	28	158.4	21.422	4.048	107	195
Total	**168**	**187.3**	**40.538**	**3.128**	**107**	**297**

TABLE IX. TUKEY HSD TEST OF LETTUCE (PARAMETER: LETTUCE HEAD WEIGHT) IN 2015 SPRING

Treatments (A)	Treatments (B)	Mean difference (A-B)	St. Error	Significance level
Control	50 mg l^{-1} Mg	-7.00 n.s.	7.761	0.946
	100 mg l^{-1} Mg	-12.29 n.s.	7.761	0.611
	150 mg l^{-1} Mg	-62.25 *	7.761	0.000
	200 mg l^{-1} Mg	-78.89 *	7.761	0.000
	250 mg l^{-1} Mg	-70.07 *	7.761	0.000

* The mean difference is significant at the 0.05 level.
n.s. = not significant

TABLE X. TUKEY HSD TEST OF LETTUCE (PARAMETER: LETTUCE HEAD WEIGHT) IN 2016 SPRING

Treatments (A)	Treatments (B)	Mean difference (A-B)	St. Error	Significance level
Control	50 mg l^{-1} Mg	35.75 *	9.753	0.004
	100 mg l^{-1} Mg	32.18 *	9.753	0.015
	150 mg l^{-1} Mg	3.00 n.s.	9.753	1.000
	200 mg l^{-1} Mg	11.39 n.s.	9.753	0.851
	250 mg l^{-1} Mg	51.11 *	9.753	0.000

* The mean difference is significant at the 0.05 level.
n.s. = not significant

The 50- and the 100 mg l^{-1} Mg treatment were not significant in 2015 spring. One year later the 150 mg l^{-1} and the 200 mg l^{-1} magnesium treatments were not significant at the 0.05 level.

We were measured the hydroponic tanks to test their EC. Changes in the electric conductivity are shown in Fig. 9 and Fig. 10. The control had the lowest EC values in repetition I. and repetition II. The highest values were obtained from the 200- and the 250 mg l^{-1} Mg treatment in repetition I. The 250 mg l^{-1} magnesium fertilizer was the highest in repetition II. (4.98 and 4.87 mS cm^{-1}).

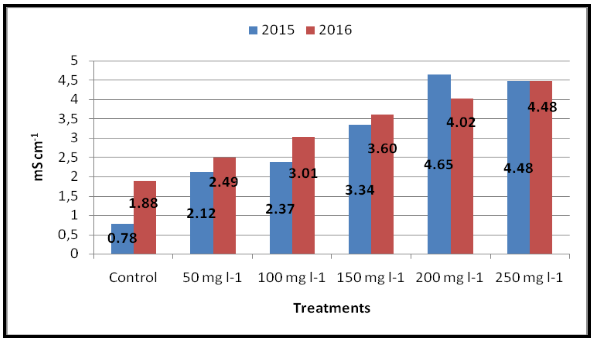

Figure 9. EC of the nutrient solutions in the treatment groups (repetition I. in 2015 and 2016 spring).

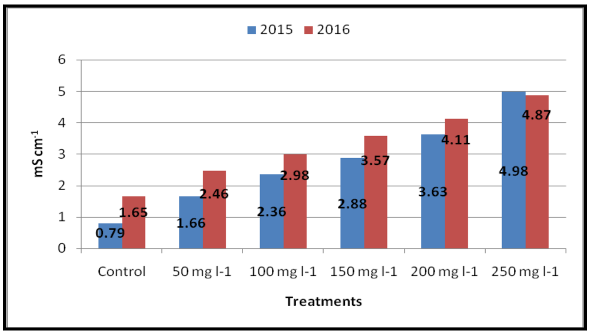

Figure 10. EC of the nutrient solutions in the treatment groups (repetition II. in 2015 and 2016 spring).

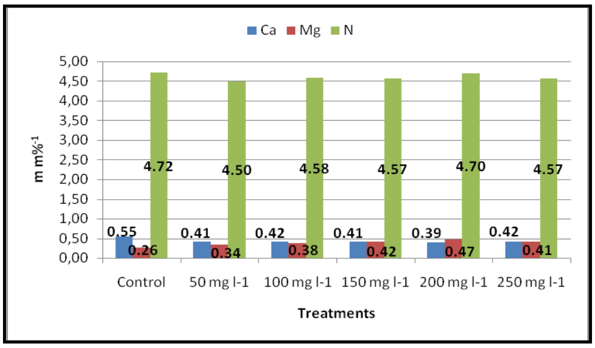

Figure 11. The nutrient element concentration (N, Mg, Ca) in the leaves of lettuce (2015 spring).

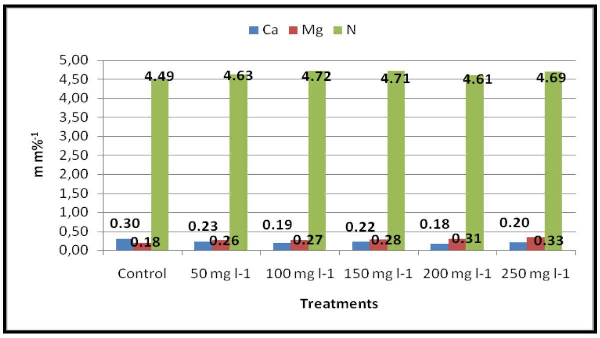

Figure 12. The nutrient element concentration (N, Mg, Ca) in the leaves of lettuce (2016 spring).

In the course of the experiment, the nutrient element concentrations nitrogen, magnesium and calcium were determined in the leaves of lettuce (Fig. 11 and Fig. 12).

The concentration of nitrogen decreased in spring of 2015, but increased in spring of 2016. The increasing magnesium concentration in the nutriment solution caused the decrease of calcium content in dry matter of the leaves in spring of 2015 and 2016. The concentration of magnesium increased in spring of 2015 and 2016, as well.

The increasing concentration of magnesium can be the consequence of the additional amounts of applied magnesium supplements, while decrease of nitrogen and calcium nutriment element concentrations can be explained by the phenomenon of attenuation.

IV. Conclusion

Despite the widely and commonly used traditional agricultural production technologies, hydroponic growing also has a great role in nowadays and in the future as well. In the course of our experiment we found that the easily purchased materials (stone wool, medium raw material) can be used cost-effectively in the hydroponic cultivation.

Human labor is only needed for planting into stone wool, filling in the nutrient solution and harvesting. More work is needed for production on a field. In the case of hydroponic growing there is no need for weeding, fertilizing or groundwork. The leaves turning brown and rotting can be avoided with using adequate nutrient solutions. Higher salt concentration or excessive nutrient ratios may easily cause inadequate growing or disorders.

The lettuce was grown using hydroponic cultivation in our study. Their growth was steady, but there was a great deviation in head weight. While measuring the hydroponic lettuce we found that the magnesium treatment led to a significant decrease in head weight, compared to the control group.

The results of autumn research on lettuce head weight were higher than that of spring results. The maximum head weight was measured in autumn results (2014). We reached 324 gram after the 100 mg l^{-1} Mg treatment. The lowest value was measured in spring (2015), 0 gram (control group, 50- and 100 mg l^{-1} Mg treatments).

As a supposed result of some antagonism, the magnesium concentration blocked the potassium uptake and thus led to the large differences in mass. Potassium is a mobile, translocating element and so the deficiency symptoms were first observed on the older leaves. The potassium deficient plants have a reduced disease resistance, chlorosis and necrosis often occurs later in lettuce. Calcium deficiency symptoms were also noticeable. The roots had insufficient growth, the apices were mucoid, they turned brown and subsequent necrosis was observed. In some cases the plant's growth did not begin, as the lettuce did not take up the nutrients at a proper rate.

The temperature and humidity of the greenhouse can be easily controlled with the automated system. The nutrient solution can also be circulated multiple times a day. The advantage of the technology is that the plants grow at the same rate and the heads are harvested at the same time. Harvesting is a short and smooth process, so it makes an efficient use of human resources. This method can be used repeatedly, allowing continuous production throughout the year. Lettuce can be grown as much as six times on stone wool in a year.

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